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SOIL CONSERVATION PROGRAMS IN THE UNITED STATES AND CANADA[1]

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Because of the widespread interest shown in recent years in the conservation of soil resources, it is desirable to outline briefly the programs being conducted throughout the United States and Canada. Obviously it is impossible to deal fully with the several projects now under way in the United States, but because of the extensive character of this work it is important to recognize the principal types being undertaken. In Canada a soil conservation program has been developed in the provinces of Manitoba, Saskatchewan, and Alberta, under the Prairie Farm Rehabilitation Act, and while this work differs in many respects from work in Eastern Canada it no doubt has some points of interest common to those interested in soils.

Soil Erosion in Ancient Empires

Dr. W. W. Reitz of the United States Soil Erosion Service at Bath, New York, has compiled a very interesting and highly instructive publication on the history of soil erosion in ancient empires. He draws attention to the curious fact that many ancient civilizations flourished in what is now absolutely desert land. Babylonia, Assyria and Persia are largely desert countries. Asia Minor, and, it is said, portions of Northern Africa, even within the boundaries of the Sahara Desert, were once thickly populated countries.

China is a country of such vast extent, and such poor and hazardous means of transportation that its interior is not well known. It is believed, however, from the testimony of informed travellers, that vast areas of that country have been utterly ruined by soil erosion. The Yellow Sea derives its name from the yellow silt carried away by the Yellow River. Centuries of farming without the use of scientific methods have permitted the erosion of the most fertile portions of the surface soil.

Soil Erosion Losses in the United States

Soil drifting has caused very serious losses in the Western States during the last few years. It has been particularly serious in the drier areas of the Great Plains States, and especially in the so-called Dust Bowl of the Texas Panhandle, Oklahoma, New Mexico, Kansas and Colorado. Dr. W. C. Lowdermilk, Assistant Chief of the Soil Conservation Service of the United States, has stated that 9,000,000 acres of land have been

[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of New Brunswick, Fredericton, N.B., July 14–15, 1936.

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seriously damaged in the United States by soil drifting. The productivity of much of this land has been completely ruined, and great discomfort has been caused to a large section of the population.

Serious as has been the loss from soil drifting, the loss throughout the entire United States by water erosion has been much greater. The Soil Conservation Service estimates that some fifty to one hundred million acres have been either seriously damaged or completely destroyed by water erosion. The total soil erosion loss in the United States from both wind and water has been estimated to amount to three billion tons of soil annually. As it is difficult to visualize such a large figure it might be of interest to express it in another way.

One acre of soil six inches deep weighs approximately two million pounds, or 1,000 tons. The loss of three billion tons of soil would equal, therefore, a loss of six inches of surface soil from three million acres of land. As such a depth is rarely removed annually, this loss would be equivalent to the removal of one inch of soil from eighteen million acres, or of one-half inch from thirty-six million acres. It is obvious that every effort should be made to prevent this loss.

The value of this soil based on the plant food constituents contained is estimated at two billion dollars. As many millions of dollars are spent annually for commercial fertilizers, and as large amounts of valuable farm manure are employed annually, it is clear that the first step should be to control the loss of the soil itself and the tremendous amount of plant constituents contained in it.

SOIL CONSERVATION PROGRAMS IN THE UNITED STATES

There are three types of soil conservation projects being conducted in the United States.

1. *The nation wide policy of bonusing all farmers for changing a portion of their crop acreage from soil-depleting to soil-conserving crops*

Under this policy farmers who divert up to 15% of their acreage of such soil-depleting crops as wheat, oats, barley, cotton and corn, to soil-conserving crops like grass, clover and alfalfa, or in certain regions to summer-fallow, contour tilled or terraced land, receive a bonus. The amount of the bonus varies in different parts of the country depending upon the productivity and earning capacity of the land. It is supposed to average approximately $10.00 per acre for the percentage of the acreage diverted to soil-conserving crops. This bonus is supplemented with other payments for certain other practices designed to maintain or improve the fertility of the soil.

2. *Special Soil Erosion Experiment Stations*

These stations have been established for the purpose of determining the amount of soil erosion under different conditions and for studying the best methods of control.

There are 13 of these special soil erosion stations located in 12 states. Some of these stations were established in 1928 while several have been added during recent years. The information secured from the experiments conducted forms the basis for the work of the larger projects.

3. *Co-operative Soil Conservation Projects with Farmers*

There are 141 of these large co-operative projects located in 41 states; 137 of the projects are on private land, and 4 are located on public land. The total area included in these projects amounts to 46,000,000 acres.

In connection with the work on these co-operative soil conservation projects with private farmers, there is considerable assistance received from 455 C.C.C. Camps (Civilian Conservation Corps). Assuming 150 men to a C.C.C. camp this means a total of 68,250 men available for work under this program.

Cohocton River Co-operative Soil Conservation Project, Bath, N.Y.

This project was started in February, 1935. It comprises an area of approximately 150,000 acres of which to date 26,000 acres are under contract. There are about 1,100 farmers in this area, 200 having already signed co-operative contracts, while an additional 400 have requested plans, and desire to sign. Each contract is for a period of five years.

One of the principal methods of soil erosion control being developed in this project is strip cropping. Instead of having large fields entirely devoted to a single crop, the land is planted to a number of crops arranged in strips running at right angles to the direction of the slope.

Wherever the slope of the land amounts to 2% or more, strip cropping is recommended. Under such a gentle slope the strips are quite wide, perhaps 300 feet each. On more level land where strip cropping is not necessary, cultivation and planting on the contour may be sufficient. Where the slope of the land is approximately 15% the strips are 100 feet in width, while under more extreme conditions they may be narrowed to about 50 feet.

There is no terracing done in this project. It is believed that strip cropping and working the land on the contour will prevent erosion. Wide diversion ditches having a slope of not more than 2% are provided to collect the water from natural depressions. The diversion ditches discharge into outlet drains where the erosion is checked by grassing the bottom or surfacing with stones. At certain intervals where the slope is steep, barriers such as piles of stone, are placed in the outlet drains, in order to prevent "wash outs".

Where gullies have been formed through severe soil erosion they are reclaimed by various methods. Sometimes brush is placed in the bottom of the gully; it is then covered with stones and earth scattered over the surface. In time this settles, and additional earth must be placed in the depression. Manure or commercial fertilizers must be applied in such places for a few years in order to promote satisfactory crop growth.

Very large gullies too seriously eroded to be reclaimed for crop production are planted to shrubs and trees. Dams are built in the gullies to check the flow of the water and diversion ditches are constructed in the upper portion of the water sheds to reduce the amount of water flowing through the gully.

Co-operative Soil Erosion Projects at Amarillo, Texas, and Colorado Springs, Colorado

These projects are located in the so-called Dust Bowl area where severe soil drifting has taken place. Dry land agriculture and ranching are practised in these regions under conditions of limited precipitation and very high evaporation.

The chief practices recommended for soil drifting control, as well as for erosion caused by water, include terracing, contour furrowing, contour cultivation, and strip cropping. It is maintained that these practices will assist not only in checking soil drifting but in reducing the amount of the run-off moisture. As moisture is such a dominant factor in crop production in this dry region every effort is made to conserve as much as possible.

Experiments and experience in the control of soil erosion have shown that the following crops may be listed in the order of their ability to resist to erosion.

1. Perennial grass crops, if there is a good stand.
2. Alfalfa and sweet clover.
3. Drilled crops of Sudan grass, sugar cane, kafir and millet.
4. Small grains.
5. Row crops of Sudan grass, sugar cane, kafir and millet.
6. Corn.
7. Beans and buckwheat.

Beans and buckwheat leave the surface of the soil in a very friable condition which is very susceptible to erosion.

The staffs of these soil conservation projects include engineers, agronomists, soil specialists, foresters, draughtsmen, accountants and clerks. In addition there are many mechanics and labourers employed as well as the young men from a large number of C.C.C. camps. After a co-operative agreement is signed with a farmer, a soil expert is sent to the farm in order to make a soil survey. A map is made of the farm showing the location of the fields, the soil type, amount of erosion, slope of the land, and the crops that have been grown in the various fields. A new plan is then prepared showing an improved arrangement of the farm including more efficient cropping and cultural practices for better soil erosion control.

SOIL CONSERVATION PROGRAM IN THE PRAIRIE PROVINCES OF CANADA

The only part of Canada where there is any large soil conservation program in progress is in the three Prairie Provinces. Owing to the severe drought and soil drifting which took place in the southern portions of these provinces from 1931 to 1934 inclusive, it was considered necessary to develop a rehabilitation program.

An Act was passed in the 1935 Session of the Parliament of the Dominion of Canada to provide for the rehabilitation of the drought and soil drifting areas of the provinces of Manitoba, Saskatchewan, and Alberta. This Act is known as the Prairie Farm Rehabilitation Act.

As a complete report of the activities being conducted under the Prairie Farm Rehabilitation Act has already been published, it is not advisable to review this program at the present time. Mimeographed reports of the program have been prepared by the Dominion Experimental Farm at Ottawa, and a brief outline was contributed by Dr. E. S. Archibald, Director of the Dominion Experimental Farms, in the May, 1936, issue of the *Engineering Journal* (Canada).

It may be stated briefly that the program comprises measures designed to control soil drifting and to conserve soil moisture. These measures

include strip farming, cover crops, surface working of the land instead of ploughing, and cultivation to leave a cloddy surface. Rotations are arranged to conserve as much moisture as possible.

District experiment sub-stations have been located in representative areas in order to demonstrate the value of the most efficient practices. Reclamation sub-stations have been established in very severely eroded areas, in order to determine whether the land in these areas should be farmed or used for ranching. Regrassing projects have been started on badly eroded areas having no vegetation cover. Tree planting projects have been commenced both for farm home shelter belts and for field crop shelter belts. A soil research program is under way in a new soils research laboratory, established on the Dominion Experimental Station at Swift Current, Saskatchewan. Soil surveys and economic surveys are being undertaken. Agricultural improvement associations have been established in order to disseminate the information as widely as possible in different parts of the country. Water development has been promoted by encouraging the construction of dug-outs, and stock watering and small irrigation dams in order to increase the supply of water for farm and ranch use.

SOIL CULTIVATION AND TILTH

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INTRODUCTION

Soil cultivation in its most primitive form was probably the first attempt to improve agricultural conditions by artificial means. It is not known how this earliest of agricultural developments began. Conjecture points to the possibility that some primitive man noticed that the seeds of wild plants, which fell upon disturbed soil, germinated and grew more vigorously than those seeds which fell on undisturbed land. This simple observation may have stirred the imagination of the first farmer-philosopher and resulted in the early art of soil cultivation. This no doubt consisted of scattering seed on the surface of soil, which had been merely scratched by means of a digging-stick, a hand tool which later became the spade. As oxen came into use, for beasts of burden, crude wooden plows were fashioned with which the soil was stirred a little deeper. Sheep and cattle were used to tramp the seed into the soil. Later bush harrows were used to produce a finer seed bed, and to cover the seeds.

Agricultural practices of this kind are known to have existed in Egypt over 4,000 years ago. While development has been slow, measured in terms of a man's life, each century has resulted in some perceptible advance. It was not until just before the opening of the nineteenth century, however, that any very rapid development took place. Until that time the plow, which was recorded on Egyptian monuments, appears to have undergone only one major change; a primitive harrow had been developed and an implement similar to the modern cultivator had been used. Aside from such developments very little progress had been made in regard to the use of farm machinery. Farm practices had advanced slightly, but much of the work was still done by hand. With the increase in industrial inventions man's ingenuity turned to the development of farm machinery. In the hundred years which have followed, very great changes have taken place in the methods used for soil cultivation. Many of these changes have been evolved from an engineering or mechanical basis rather than from the aspect of soil tilth or soil science.

Although the art of soil cultivation, as it stands today, has been many hundreds of years in developing, this very long history may have been responsible for retarding its development in modern times. Soil improvement workers have been inclined to neglect this phase of soils work, possibly assuming that over such a long period soil cultivation must have been brought almost to its zenith. The newer sciences of soil fertility and soil classification have more or less overshadowed the art of soil cultivation and tilth.

It is an odd circumstance that for many centuries the plow of the Egyptians remained essentially a soil stirring implement. One possible explanation for this lack of development in the plow may have been that

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there was little incentive to depart from a soil stirring tool for the type of agriculture practised in North Africa and parts of Southern Europe. The idea of applying a mould-board to turn the soil to one side appears to have originated with the Saxons under a different type of agriculture in Northern Europe. It is known that the Saxon introduced his own plow into Great Britain, and available evidence suggests that it is from that implement, and from nothing that preceded it, that our present day plow evolved.[3] It may not be a coincidence that the modern cultivator, a soil stirring implement, has come into vogue in our semi-arid grain producing regions, while the plow still holds first place in the more humid areas, or where cultivated grass lands are extensive. It may well be that in the search for truth we should not disregard the lessons of history.

PRESENT DAY PROBLEMS

The primary object of this paper is to bring to the attention of soils workers in Canada the need for more scientific work pertaining to soil cultivation and tilth. The most suitable methods of cultivation for the maximum growth of various species of plants, on widely different soil types, is certainly not known. Indeed the optimum degree of tilth in relation to these points and environmental factors is not known, nor is there a satisfactory method of measuring tilth which can be used for comparative purposes.

That some desirable degree of tilth is required for maximum crop production is, of course, an accepted fact. The preparation of the seed bed constitutes the most expensive single item in the cost of producing crops. More primary power is used in agricultural production than in any other industry with the exception of transportation. Tillage operations are among the greatest consumers of power. Plowing consumes more power than any other single operation in seed bed preparation. With the common type of mould-board plow the soil is cut, lifted, inverted and partially pulverized; an operation which consumes thousands of foot-pounds of energy per acre. The deeper the plowing the greater the expenditure of energy. It is estimated that over eight million acres are plowed each year in Eastern Canada.

Other tillage implements such as cultivators, discs, harrows, weeders, and seeders, which of necessity must be dragged through the soil, are tremendous consumers of power, more so than harvesting machinery for instance, which although frequently more intricate, usually have rolling parts and are drawn over the ground rather than through it. When the cost of power used in tillage is considered in its relation to the cost of producing crops, it would seem worthy of a considerable amount of scientific investigation, in fact more consideration than is being given to this phase of soil science in Canada at the present time.

Every inch added to the depth of plowing beyond that which is required for maximum economic crop production, adds unnecessarily to the already high cost of soil tillage. Each time a disc or cultivator passes over a field, after it has reached that degree of tilth most desirable for plant growth, the efficiency of the farm management program is reduced. How can the most suitable method of tillage, and the most desirable degree of tilth be determined? This is a question of great economic importance

[3] Spencer, A. J., Passmore, J. B. Agricultural Implements and Machinery, Science Museum, South Kensington, Eng. 1930.

to those engaged in crop production, and to those responsible for the design and manufacture of machines for tillage purposes.

Various methods have been attempted to express the measurement of tilth, and also the resistance of soils to tillage. There is still a need for such a definite unit of measurement. Since, however, the primary object of tillage is to produce conditions favourable to plant growth, the ultimate test of tilth must be the plant. It would seem, therefore, that all cultural or tillage investigations should be subject to this final check of the effect upon the plant itself.

INVESTIGATIONS ON THE DOMINION EXPERIMENTAL FARMS

The Dominion Experimental Farms are doing a considerable amount of work in connection with tillage methods. The results of some of these experiments are presented, comparing the effect of various tillage operations, based on the yield of crops following each individual treatment.

Time and Method of Plowing Sod Land for Grain

Experiments to determine the best time and method of plowing sod land for grain have been conducted at Ottawa, Ont., Lennoxville, Que., Nappan, N.S., and Charlottetown, P.E.I. In these experiments the relative effect of different times and methods of plowing timothy sod on the succeeding yield of oats has been determined in a five-year rotation of hoed crop, oats, clover, timothy, oats. At Ottawa and Lennoxville the hoed crop has been corn, while at Nappan and Charlottetown turnips were used. At each of the Stations the rotation received 20 tons of manure per acre during each five-year period. The average yield of oats following timothy is presented in Table 1 for each of the treatments employed.

TABLE 1.—TIME AND METHOD OF PLOWING TIMOTHY SOD FOR GRAIN

Soil treatment	Average yield of oats following timothy, bushels per acre				
	Charlottetown	Nappan	Ottawa		Lennoxville
	Sandy loam over clay 15 years	Clay loam over clay 11 years	Sandy loam over clay 10 years	Heavy clay 13 years	Sandy loam over gravel 12 years
Plowed 6 inches deep August, top-worked	39.9	49.5	—	51.2	39.7
Plowed 6 inches deep August, top-worked, ribbed	40.2	53.7	47.4	49.7	39.1
Plowed 6 inches deep September, top-worked	39.1	52.2	—	—	—
Plowed 6 inches deep October, top-worked	36.7	50.9	—	—	—
Plowed 6 inches deep October, not top-worked	37.5	51.2	36.1	49.4	34.1
Plowed 6 inches deep Spring	28.5	49.1	36.9	39.2	32.4
Plowed 3 inches deep August, top-worked, replowed late Autumn	38.5	51.9	39.6	—	36.0

Spring plowing of sod land has produced lower yields of oats on all Stations than has fall plowing, except on light land at Ottawa. On light land at Ottawa the difference between spring and fall plowing of timothy sod for oats has not been significant.

Plowing timothy sod in the summer, followed by top-working either with or without subsequent ribbing of the land in the late fall, has resulted in the highest yields of oats on all stations, with the exception of Nappan. At this farm ribbing of summer-plowed land produced the highest yields of oats, while on unribbed summer-plowed land the yield of oats has not been significantly superior to that on spring-plowed land.

In general the results of this experiment indicate that summer plowing of timothy sod with subsequent top-working during the remainder of the summer has been the most suitable treatment for oats. This is particularly true where perennial weeds, such as couch grass, are troublesome. Where no weeds are present late fall plowing is usually quite satisfactory.

Preparation of Hoed Crop Land for Oats

Experiments to determine the best method of preparing hoed crop land for oats have been in progress at Nappan and Charlottetown for periods of 13 and 15 years respectively. The rotation used in these experiments is swede turnips, oats, clover, timothy, oats, at Charlottetown, while sunflowers instead of swedes have been used in the first year at Nappan. Manure is applied in these rotations at the rate of 20 tons per acre in each five-year period. The average yield of oats following hoed crop under the different treatments at the two Stations is presented in Table 2.

TABLE 2.—PREPARATION OF HOED CROP LAND FOR OATS

Treatment of hoed crop land	Charlottetown	Nappan
	Oats after sunflowers 15 years	Oats after swedes 13 years
	(bu. per acre)	(bu. per acre)
No fall treatment, disked in spring	45.6	62.6
Plowed 3″ deep in spring	44.7	62.1
Ribbed in fall, not plowed	44.8	59.4
Plowed 3″ deep in fall	44.3	58.7

The results secured from different methods of preparing hoed crop land for oats at Charlottetown and Nappan, as presented in Table 2, would indicate that plowing is not necessary from a cultural standpoint, and best results were obtained from disking the land in spring with no fall treatment. Shallow plowing in spring was also better than any fall treatment. Plowing of hoed crop land for grain is not generally recommended. This is particularly true where annual weeds are troublesome. The hoed crop, if properly hoed and cultivated, will have destroyed weeds which have grown from the weed seeds located near the surface of the ground. Plowing, if done at all deeply, would turn the comparatively weed-free surface soil down, and expose a layer of soil from a lower depth, carrying

a fresh supply of weed seeds which would germinate to infest the grain crop following. Disking or shallow cultivation of hoed crop land for grain would not bring these weed seeds to the surface and is, therefore, recommended, unless plowing may be required for the control of certain insects.

Seed Bed Preparation for Grain

The preparation of the seed bed for crops is a matter which may have quite a considerable influence upon the economics of crop production. Unnecessary cultivation adds to the cost of producing a crop. In order to learn what effect different amounts of cultivation in the preparation of a seed bed has upon the yield of oats, an experiment was begun at Ottawa in 1922, at Charlottetown in 1921, and at Nappan in 1930. At Ottawa and Nappan the experiment is conducted in a rotation of oats, oats, clover, while at Charlottetown the rotation is potatoes, oats, clover. In each instance the land is fall plowed for the seed bed treatments for oats.

Three different treatments have been compared in this experiment. One treatment has been termed poor cultivation in which the land is disked once, harrowed with a spike-tooth harrow, seeded and harrowed after seeding. The second treatment which is termed ordinary cultivation consists at Ottawa of cultivating once, disking once, harrowing with spike-tooth harrow, seeding and harrowing. At Nappan and Charlottetown the treatment is similar except that instead of cultivating and disking, the disk is used twice with no cultivating as at Ottawa. The third treatment, which has been termed extra cultivation consists at Ottawa of cultivating, disking, harrowing, seeding, rolling, harrowing and rolling when the grain is 6 inches high. At Charlottetown the treatment is similar except the land is double disked instead of cultivating and disking. At Nappan the treatment is disk twice, harrow, seed, roll and harrow. The results at the three stations are shown in Table 3.

TABLE 3.—SEED BED PREPARATION FOR GRAIN

Station	Years average	Average yield per acre					
		Oats after clover			Oats after oats		
		Poor cultivation	Ordinary cultivation	Extra-ordinary cultivation	Poor cultivation	Ordinary cultivation	Extra-ordinary cultivation
		bu.	bu.	bu.	bu.	bu.	bu.
Ottawa	8	48.5	50.0	49.1	44.6	44.9	44.4
Nappan	5	55.0	53.4	48.5	38.5	43.3	40.0
Charlottetown	15				*44.7	42.7	42.4

* Oats after potatoes.

A valuable finding from this experiment is that ordinary cultivation has given fully as large yields of oats after clover as extraordinary cultivation. Following oats or potatoes the soil is more friable and does not require as much cultivation as the comparatively tough clover sod. It is doubtful whether more than the minimum amount of seed bed preparation is

beneficial on fall plowed stubble or hoed crop land. The clover in the rotation at Ottawa and Nappan has not been influenced to any extent and the yields of clover have been almost equal on all treatments. At Ottawa the experiment was conducted on very heavy clay soil where extra cultivation might be expected to give better results than on lighter soils. It would appear, therefore, that in preparing a seed bed it is advisable to cultivate as little as possible providing a suitable seed bed is obtained. Any additional cultivation simply adds to the cost and provides little or no benefit in increased yields. It delays the time of seeding, moreover, a factor which is very important and will, unduly retarded, greatly reduce the yield.

Preparation of Land for Silage and Root Crops

Eleven years' results are available at three stations in Eastern Canada in regard to the preparation of sod land for hoed crop. At Ottawa and Lennoxville the rotation followed has been corn, oats, clover, timothy with the timothy sod being plowed at various dates for the corn. At Nappan sunflowers was the hoed crop in one case and turnips in another, the other three years of the rotation being the same as at the other two stations. Manure has been applied at the rate of 16 tons per acre for the hoed crop in each location. The experiment has been conducted on both loam and clay soils at Ottawa.

TABLE 4.—AVERAGE YIELD PER ACRE OF CROP FOLLOWING TIMOTHY IN A FOUR-YEAR ROTATION, HOED CROP, OATS, CLOVER, TIMOTHY

—	Corn			Sunflowers	Turnips
	Ottawa		Lennoxville	Nappan	Nappan
	Loam soil	Clay soil	—	—	—
	6 years	13 years	13 years	13 years	13 years
	tons	tons	tons	tons	tons
Fall plowing	12.44	12.76	13.39	15.81*	17 21*
Spring plowing	10.19	10.38	13.62	15.12	14.74
Plow summer, top-work fall	14.75	—	—	—	—
Plow summer, top-work fall	—	11.92	10.89	16.86	18.67
Plow summer, top-work, rib	—	13.16	—	—	—
Fall plow, manure in spring, disk-in	—	—	11.60	—	—
Plow summer, top-work, do not replough	—	—	—	16.73	19 27

*Twelve year average.

In the experiments at Ottawa and Nappan the results show summer plowing with subsequent top working to be the most suitable preparation of the soil for hoed crops. This treatment is particularly beneficial where couch grass is prevalent as is shown by results on loam soil at Ottawa. In the Ottawa experiment very little couch grass is evident where summer and fall plowing is practised, but it is troublesome on the fall plowed area

and much more serious on spring plowed land. Spring plowing has been the least desirable at Ottawa and Nappan. On Light soils spring plowing produces better results than on heavier soils. In fact, at Lennoxville, on comparatively light gravelly soil, spring plowing has produced slightly superior results to those obtained from fall plowing. On heavy soils clay spring plowing is not recommended. Summer plowing and top working of sod land for corn at Lennoxville has resulted in considerably lower yields than spring or late fall plowing.

Depth of Plowing

The Dominion Experimental Farms have undertaken experiments on four experimental farms in Eastern Canada to learn what depth of plowing will give the best results. Sod land has been plowed to various depths, followed by corn on two farms and oats on two other farms. At Ottawa fall plowing experiments have been conducted for a ten-year period as a preparation for corn on both light and heavy soil. At Lennoxville spring plowing for corn has been in progress for 11 years. At Nappan both spring and fall plowing for oats has been carried on for 13 years, while at Charlottetown fall plowing for oats has been conducted for a period of 15 years.

Table 5.—Effect of depth plowing sod land on following crop

Depth of Plowing	Ottawa, Ont. (10 years)		Lennoxville, Que. (11 years)	Nappan, N.S. (13 years)	Charlottetown, P.E.I. (15 years)
	Light soil	Heavy soil			
	Corn (tons)	Corn (tons)	Corn (tons)	Oats (bus.)	Oats (bus.)
	Fall plowing		Spring plowing		Fall plowing
3 inches					34.5
4 inches	18.04	12.46	14.59		
5 inches				44.2 spring 51.9 fall	33.9
7 inches	18.34	12.36	13.44	48.5 fall	34.2
9 inches				50.2 fall	35.3

The results of these experiments have shown that shallow plowing of three and four inches in depth has given yields fully as large as those secured from plowing seven and nine inches in depth. Similarly, sub-soiling has proven of little value under most conditions. Obviously, therefore, shallow plowing is preferable to deep plowing as it entails less expense.

These results were obtained when plowing sod land in preparation for corn or oats. Similar results have been secured also when preparing corn or root land for a grain crop the following year. In fact, under these conditions, discing alone gives yields fully equal to those obtained from plowing and is preferable to plowing where annual weeds are prevalent. Only in districts where the corn borer is present should the corn stubble be plowed under.

It is interesting to consider the results of tillage experiments, as indicated by depth of plowing, in relation to the results of certain crop sequence experiments. It has been found at Ottawa, for example, that alfalfa, a deep rooted plant, is a good preceding crop for oats. This is usually attributed to an improvement in soil fertility due to the legume. But, it has been found, also, that hemp, a deep rooted annual, is a good preceding crop for oats on comparatively weed-free land. This suggests that plant roots may exert an influence on soil tilth that may not be economically obtainable through deep tillage methods.

Type of Plows

In order to secure information on various types of plows an experiment was commenced at Ottawa in 1934 comparing the mould-board plow, the high cut plow, the disc plow and one-way disc in a rotation of corn, oats, barley and clover on which draft, weed control and crop yield data may be secured. This experiment permits plowing sod land for corn, corn land for grain, and grain stubble land for grain. Available crop yields, for one year, indicate that there is very little difference in yields following treatments with various types of plows. Sufficient records have not yet been secured, however, to decide definitely on this point.

In some parts of Eastern Canada a large number of disc plows have been sold. Many farmers are enthusiastic about the merits of this type of plow. Formerly, the eisc plow was used only on sticky gumbo soil where a mould-board plow would not clean. Its use was confined entirely to this type of clay soil in Western Canada. With the introduction of the disc plow in Eastern Canada it would seem desirable to secure definite information in order to decide under what circumstances its use is justified. A series of field experiments were conducted in 1933 to determine the draft, fuel consumption, quality of work and the effect on weed control of various types of plows. Table 6 shows the comparative draft in pounds per foot of width for both the mould-board and disc plow when operated at 3 to 4 and 6 to 7 inches deep on alfalfa sod and corn stubble land.

Table 6.—Comparative draft of mould-board and disc plows

Depth plowed	In pounds per foot of width in clay loam soil		
	Type of land	Mould-board	Disc plow
3–4 inches	Alfalfa sod	433	455
6–7 inches	Alfalfa sod	683	711
3–4 inches	Corn stubble	425	411
6–7 inches	Corn stubble	520	523
3–4 inches	Corn stubble dry and hard	450	422
6–7 inches	Corn stubble dry and hard	825	733

These field tests indicate that under ordinary conditions there is not much difference in the draft of the mould-board and disc plow. Under dry and hard conditions the disc plow required slightly less draft than the mould-board plow.

The apparent quality of the work done with the two types of plows on sod and stubble land showed the mould-board plow to turn a comparatively smooth furrow while the disc plow turned the soil in clods, making its work appear very rough. Considerable grass was observed on the surface where the disc plow was used on sod land. About 4% of these grass tufts grew in the spring after plowing as compared with 2% where the mould-board plow was used. On very wet soil, sand or muck, the disc plow has a tendency to bury itself. The depth of plowing cannot be maintained as uniformly as with the mould-board plow. It would appear that there is not quite as wide a range of conditions in which the disc plow will operate successfully as is the case with the mould-board plow. This plowing experiment is being continued to secure more definite information on the quality of the work done under different conditions and on the yield of crops following the use of various types of plows.

Résumé

Culture et ameublissement du sol. P. O. Ripley et J. M. Armstrong, Ferme expérimentale centrale d'Ottawa, Ont.

Il a été fait des recherches aux Fermes expérimentales fédérales de l'Est du Canada sur la préparation de la terre qui doit être ensemencée en grain, et les recherches ont donné lieu aux constatations suivantes: Sur chaume de mil (fléole des prés) le labour exécuté en été et suivi par des scarifiages est la meilleure préparation pour l'avoine, spécialement sur terre infestée de mauvaises herbes. Après une récolte sarclée le labour n'est pas nécessaire pour l'avoine; on obtient de meilleurs résultats en pratiquant un disquage au printemps, sans façons culturales d'automne. D'autre part, après une récolte de trèfle, une préparation ordinaire de la terre destinée aux semailles de grain a permis d'obtenir des rendements d'avoine tout aussi élevés qu'une préparation extraordinaire. Sur terre franche la meilleure préparation pour une récolte d'ensilage ou de racines est le labour d'été, suivi de façons de surface. En ce qui concerne la profondeur du labour exécuté sur chaume, en préparation pour la culture du maïs ou de l'avoine, le labour superficiel à trois ou quatre pouces de profondeur a donné des rendements beaucoup plus forts que le labour pratiqué à des profondeurs de sept et neuf pouces. D'autre part, les recherches sur l'alternance des récoltes portent à croire que les plantes profondément enracinées exercent sur l'ameublissement du sol un effet que l'on ne pourrait obtenir économiquement par des méthodes de culture profonde Des essais de charrue indiquent qu'il n'y a pas beaucoup de différence dans la traction par pied de largeur entre la charrue ordinaire et la charrue à disques, dans les conditions ordinaires. Lorsque la terre est sèche et dure, la charrue à disques exige un peu moins de traction que la charrue à versoir ordinaire.

METHODS OF APPLYING COMMERCIAL FERTILIZERS[1]

W. S. Blair[2]

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The work with the placement of fertilizers covered in this report was started at the Experimental Station, Kentville, N.S., in 1930, with potatoes. It covers five years with potatoes and three years with turnips, corn, and mangels. The results are the average of duplicate plots. The soil throughout was similar and very uniform, and previously had been handled with the same crops each year, with similar treatment throughout.

The method of culture of the crops used in this placement of fertilizer test was similar from year to year, the only difference being in the rates of fertilizer used and the methods of application. The fertilizer was a 4-8-10 mixture valued at $24 per ton. Two rates of application were made: 750 and 1,500 pounds per acre for potatoes, turnips and mangels, and 500 and 2,000 pounds per acre for corn. The preparation of the soil up to the time of applying the fertilizers was the same for the whole area.

PLACEMENT OF FERTILIZER

Five methods of application have been under test, as follows:—

1. *Broadcast Placement.*—The fertilizer was scattered evenly on the surface and worked into the soil to a depth of two inches.

2. *One Inch Below the Seed and Covered with One Inch of Soil.*—The potato rows were opened up to 4 inches below the soil level and the fertilizer scattered along the bottom and covered with one inch of soil, the sets placed and the rows ridged over the sets. The turnip and mangel rows were ridged up as with a horse hoe and rolled. This ridge was opened with a hand marker to a depth of 3 inches and the fertilizer placed in the opening and covered with one inch of soil. The seed was sown and covered to the usual depth. The corn was sown on the level by opening the soil with the marker to a depth of 3 inches, placing the fertilizer and covering it with one inch of soil, sowing the seed and covering it.

3. *Placement in Side Bands 3 Inches at Each Side of the Seed.*—The potatoes and other seeds were sown and trenches opened up with a marker 2 inches deep at each side of the row, into which the fertilizer was placed and covered. In the turnip test this placement was made on level soil and the turnips seeded on the level, a corresponding check plot not fertilized being similarly made.

4. *Placement in Contact with Seed.*—The opening was made on the top of the firmed, ridged row to the required depth, the fertilizer applied and slightly mixed with the soil, and the seed planted in practically direct contact with the fertilizer.

5. *Deep Application of Fertilizer.*—This was used with turnips. Openings were made to 8 inches below the top of the ridge and the fertilizer scattered and covered with soil, the row firmed, and the seed planted.

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[1] Read before a session of the Soils Group of the Canadian Society of Technical Agriculturists at the University of New Brunswick, Fredericton, N.B., July 14–15, 1936.

[2] Superintendent.

In every case there were two corresponding plots not fertilized to serve as checks.

To arrive at the value of the gains the following prices were allowed: potatoes, 40 cents, turnips and mangels, 10 cents, per bushel; and fodder corn, $4 per ton. A summary of the results is given in Table 1.

TABLE 1.—FERTILIZER PLACEMENT TESTS

Method of placement	Rate: 750 pounds per acre		Rate: 1500 pounds per acre		Difference in yield
	Yield	Value of gain	Yield	Value of gain	
	bush.	$	bush.	$	bush.
Potatoes, 5 years					
1. Broadcast	242.9	5.16	264.0	4.60	21.1
2. One inch below seed	268.4	15.36	302.0	19.80	33.6
3. Bands at side of row	296.4	24.56	320.5	27.20	24.1
4. In contact with seed	271.7	16.68	264.5	4.80	− 7.2
No fertilizer	207.5				
Turnips, 3 years					
1. Broadcast	806.4	21.30	826.6	14.32	20.2
2. One inch below seed	791.4	19.80	898.1	21.47	106.7
3. Bands at side of row	852.2	29.05	933.3	28.15	81.0
4. In contact with seed	818.1	22.47	681.4	− 0.20	−136.7
5. Deep application	825.6	23.22	954.7	27.13	129.1
No fertilizer, on level	471.8				
No fertilizer, ridged	503.4				
Mangels (1500 lb., 2 years; 750 lb., 1 year)					
1. Broadcast	859.7	41.77	652.2	12.02	−207.5
2. One inch below seed	832.0	39.00	804.3	27.29	− 27.7
3. Bands at side of row	940.8	49.88	890.2	35.82	− 50.6
4. In contact with seed	797.7	35.57	717.0	18.50	− 80.7
No fertilizer	352.0				
Fodder Corn, 3 years	500 pounds		2000 pounds		
	tons		tons		tons
1. Broadcast	15.34	4.28	16.77	− 8.00	1.43
2. One inch below seed	14.91	2.56	15.59	−12.72	.68
3. Bands at side of row	14.56	1.16	17.61	− 4.64	3.05
4. In contact with seed	14.16	− .44	12.59	−12.72	− 1.57
No fertilizer	12.77				

The difference in crop response to the increased fertilizer was not great. In order to pay for the extra fertilizer used above the lower rate of application, the increase in yield would have to be 22.5 bushels of potatoes, 90 bushels of turnips or mangels, and 4.5 tons of corn. It is evident that only in a few cases has this expense for extra fertilizer been profitable. In some cases there has been a decided loss, particularly with the heavy applications in contact with the seed and where the heavy applications were made to corn.

DISCUSSION

In the broadcast applications the fertilizer was mixed with the surface soil, and where drills were run it would be drawn into the row for making the ridge, thus placing practically all the fertilizer well distributed into the row. This practice, one would think, should give the best distribution and be the most practical, and is certainly the easiest of all methods.

The placement of fertilizer below the seed is not a practical method for the reason that the placement of the fertilizer, the covering of it evenly with a layer of soil and planting of the seed cannot well be done in one operation.

The placement of bands at the side of the rows is a practical method and one which has been adopted in the later makes of row-planting machines. It is more difficult so to place fertilizers in the case of a narrow space between the rows, as in grain seeding.

The placement of fertilizer in bands so that it comes into direct contact with the seed is not a good practice, as it is very likely to stunt the plant at the time of germination, and a plant stunted when young rarely makes satisfactory later growth. This is not so pronounced in light as in heavy applications. The failure in many gardens from seed not starting is directly traceable to fertilizer injury. Invariably heavy applications are made which are not thoroughly incorporated into the soil, and the seeding shows a dwarfed, unhealthy appearance from the start. The band method of applying fertilizer should be generallv adopted in vegetable garden culture, and the fertilizer placed in bands 2 to 3 inches deep and 3 inches away from the row of seedlings. In the early life of seedlings they are nourished by the seed and require little plant food, and by the time they are well established the plant food in bands is readily available to them.

CONCLUSIONS

Much injury to plants when young resulted from the contact applications This was also evident in suppressed later growth.

The broadcast applications were not as good as the band placements.

The placement of fertilizers in a single narrow band below the seed and covered with one inch of soil has given good results.

The placement of fertilizer in two narrow bands, one at each side and three inches from the seed, and two inches deep in the soil, gave the best results.

Heavy applications of fertilizers have not been as satisfactory as lighter applications for evaluating the effect of different methods of application.

OTHER EXPERIMENTS

A one-year test made at Kentville with oats, using 500 pounds of 4-8-10 fertilizer per acre, gave a good stand from all the methods with practically no difference in yield although the fertilizer placed along the sides of the grain rows yielded 3 bushels less per acre than that where fertilizers were scattered broadcast and harrowed in before seeding: broadcast, 62.2; below seed one inch, 61.3; side placement, 59.3; contact, 61.2; and not fertilized, 44.03, bushels per acre.

Experiments at Ottawa in progress since 1929 with cereals indicate that drill applications of fertilizer with seed at the rate of 200 pounds per acre gave us good results as 400 pounds when sown broadcast. In the case of silage corn, band placement of the fertilizer at each side of the row and level with the seed gave higher yields than applied broadcast, and drilling in with the seed injured germinating plants.

Experiments at Fredericton with potatoes show that the planting of sets in direct contact with the fertilizer affected the stand, and that broadcast applications gave the best stand. Fertilizer applied in the row and mixed with the soil gave the best yield.

Work in the United States would indicate that with potatoes the highest yields are possible from ribbon side-dressings, about 3 inches each side of the set and slightly below seed piece. The furrow application with free soil between the seed piece and fertilizer was second and the lowest yields were obtained when fertilizer was applied in the furrow and lightly mixed with the soil. In general, side placements seem to give the best yields.

Résumé

Modes d'application des engrais chimiques. W. S. Blair, Station expérimentale fédérale de Kentville, N.-E.

Les engrais chimiques appliqués en contact direct avec les plantules ont beaucoup nui à ces dernières dans les premières phases de la pousse, et enrayé leur développement plus tard. Les applications à la volée ne valent pas les applications en bandes. On croit que lorsque l'engrais est distribué de façon égale, le phosphore peut devenir inactif en retournant rapidement à une forme insoluble. Le placement des engrais en une seule bande étroite, au-dessous de la semence, et recouverte d'un pouce de terre a donné de bons résultats, mais le meilleur système est celui qui consiste à placer l'engrais en deux bandes étroites, une de chaque côté de la semence et à trois pouces de celle-ci, et à deux pouces de profondeur dans le sol. Au point de vue de l'évaluation de l'effet des différents modes d'application, les fortes applications d'engrais ne valent pas les applications plus légères.

THE ROLE OF ELEMENTS OTHER THAN NITROGEN, PHOSPHORUS AND POTASSIUM IN CROP PRODUCTION[1]

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REVIEW OF LITERATURE

Plants in their normal growth and development take up from the soil through their roots a number of elements. At one time it was thought that only ten chemical elements were essential to plant growth, *viz.*, carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, iron and sulphur. During recent years, however, experimental work has shown that certain other elements—notably boron, copper, manganese and zinc—are also necessary for the normal development of plants. This knowledge has stimulated investigators to try to determine the role of a number of other elements in plant nutrition. A few of these elements have been found to be positively toxic to plants even in minute concentrations; some have been found to be non-essential, but non-toxic, and in the case of a few others there is some slight evidence that they may be necessary in very minute quantities.

The importance of nitrogen, phosphorus and potassium in plant nutrition is well known and a very large amount of research and experimental work has been carried on in all countries of the world to study the relative fertilizing value of various sources of these elements and to determine the amounts necessary to promote maximum production of crops under varied conditions of soil and climate. Large manufacturing plants have been established to supply the increasing demands of growers for carriers of these three elements and legislation has been passed to control the sale of commercial fertilizer and thereby to protect the purchaser. While the use of nitrogenous, phosphatic and potassic fertilizers may well be regarded as fundamental in the fertilization of crops, there are instances in which it has been found necessary to take account of the plant requirements of other elements. It is the purpose of this paper to review briefly the place of calcium, magnesium, sulphur, iron, manganese, copper, zinc and boron, in plant nutrition and to outline some results obtained during the past year from the application of "trace elements" at the Dominion Experimental Station at Kentville, N.S.

Calcium

A deficiency of available calcium in the soil usually leads to a stunting and discolouring of the root and brown spotting and subsequent death of the leaves. There are some cases reported in the literature where growing plants have suffered from calcium deficiency. In the coastal plains region of southeastern United States, tobacco plants have shown diseased conditions which responded to small additions of calcium, and even the amount of this element present in superphosphate has been found sufficient to prevent the trouble.

[1] Read before a joint session of the Soils Group of the C.S.T.A. and the Canadian Phytopathological Society at the University of New Brunswick, Fredericton, N.B., July 14–15, 1936.
[2] Chemist.

The greatest use of calcium compounds in agriculture is in improving the reaction of soils. Liming of acid soils brings about better conditions for microbiological activity and also renders insoluble such toxic substances as aluminium and manganese. Toxicity due to the presence of excess magnesium can be corrected by the addition of calcium. The benefits to crop growth through the judicious use of lime compounds are well known and further discussion of this function of calcium is unnecessary. On the other hand, over-liming may bring about a chlorotic condition in plants by rendering iron and manganese unavailable. Sometimes excess lime in the soil may interfere with the uptake of potassium.

Magnesium

Magnesium is an important plant food element since the chlorophyll of plants is a magnesium compound. Consequently magnesium-starved plants become blanched and shed their leaves prematurely.

Magnesium deficiency has been known to cause ill effects in tobacco, potato, cotton and other crops. The disease known as "sand drown," so-called as it is most prevalent on sandy loams during seasons of heavy rainfall, has been attributed to leaching of soluble magnesium compounds from the surface soil. Some investigators claim that the heavy application of potash fertilizers accelerates leaching of magnesium.

Symptoms of a shortage of available supplies of this element have been observed in certain soils of the Atlantic seaboard from Maine to Florida, chiefly in the coastal plain area.

The amount of replaceable magnesium which is necessary for normal plant growth probably varies with the crop. Beaumont and Snell (1) working with various crops conclude that a soil should contain from 30 to 40 parts per million of easily replaceable magnesium to avoid magnesium deficiency. The analysis of the soil from an experimental area at the Experimental Station, Frederiction, N.B., where no marked increase in yield of potatoes followed the application of magnesium sulphate, showed that it contained an average of 84 p.p.m. of replaceable magnesium..

In the potato growing districts of New Brunswick, symptoms of magnesium deficiency have recently been observed and an extensive study of its occurrence in that province has been conducted by MacLeod, Plant Pathologist at the Fredericton Station, and by Taylor, of the Provincial Department of Agriculture. Taylor (2) reports that the response of crops to applications of magnesium varies greatly on different farms in the same territory and appears to be greatest where commercial fertilizer has been used extensively. Further, his examination of numerous soils by microchemical methods showed that in some cases the soil contained as low as two pounds of available magnesium per acre and that when the soil contained 36 pounds or over per acre, symptoms of magnesium deficiency were not in evidence.

A very satisfactory method of overcoming magnesium deficiency is a very light application of ground dolomitic or magnesian limestone.

Sulphur

Sulphur is another of the essential constituents of plants which is sometimes a limiting factor in plant growth. Omission of sulphur from solution cultures has led to spotting of the leaf and discoloration of the root.

Sulphur is added to the soil in rain water and also in some of the more common fertilizers, *e.g.*, sulphate of ammonia, sulphate of potash and superphosphate.

There is evidence that sulphur applied in fertilizers as the sulphate has resulted in pronounced increases in crop yields. However, comparatively few cases of actual sulphur deficiency under natural conditions have been reported. Pahala blight of sugar cane in Hawaii has been effectively controlled by applying this element. A disease of the tea bush in Nyasaland was traced to sulphur deficiency. At the Illustration Station at Cheddarville in North Western Alberta, W. H. Fairfield (3), of the Dominion Experimental Station, Lethbridge, Alberta, demonstrated that a small application of flowers of sulphur resulted in very substantial increases in the yield of sweet clover on the grey bush soils of that district, and this has since been corroborated by Newton (4), of the Soils Department of the University of Alberta.

As elemental sulphur becomes oxidized in the soil to sulphuric acid, it is sometimes applied to bring about a change in soil reaction in the direction of greater acidity.

Iron

Iron plays an important part in chlorophyll formation, although chlorophyll itself is not an iron compound. Consequently lack of iron is shown by a pronounced chlorotic condition of the leaves of plants. Although most soils contain plenty of iron for plant requirements, it would appear that under certain conditions, chiefly on highly calcareous soils or on soils which have been heavily limed, this element may be unavailable to plants. Lime-induced chlorosis may be lessened by the application of a soluble iron salt to the soil or to the plant in the form of a spray.

Manganese

The presence of manganese in plants has been known for many years. Although some workers had suspected that it might have an important part in plant nutrition, it remained for McHargue (5), of the Kentucky Experiment Station, working with a large number of different species of plants, to show definitely the essential nature of this element in the growing of plants to maturity. Since then his work has been corroborated by others and at the present time the importance of manganese as a plant nutrient is generally accepted.

Usually there is sufficient manganese in the seed to give normal growth for six or eight weeks. Manganese deficiency is indicated by the development of a chlorotic condition of the leaves and retardation of growth. It is believed that manganese, as well as iron, plays an important part in the formation of chlorophyll.

Manganese is seldom if ever deficient in a naturally acid soil; indeed cases of toxic effects on plant growth from excessive amounts of available manganese in strongly acid soils have been reported. However, manganese is likely to become unavailable in calcareous or heavily limed soils and in such cases beneficial results may be obtained by the application of soluble manganese salts or by changing the reaction of the soil towards greater acidity, *e.g.*, by applications of sulphur. On the organic soils of

the Florida Everglades, the application of manganese salts is needed only on soils with excessive amounts of lime.

Certain specific diseases of plants are regarded as due to manganese deficiency. Pahala blight of sugar cane in Hawaii and a disease of lemon plants in Italy were both cured by manganese salts. Treatment of grey speck or halo blight of oats with manganese compounds has been successful in Wales, Germany, Australia and other countries. At the Central Experimental Farm, Ottawa, failure of the oat crop in small localized patches has been prevented by applications of manganese sulphate.

Copper

Copper is invariably present in plants, although it is only within the last few years that it has been thought to be essential to plant life. Analyses show that seeds have a higher percentage of copper than other parts of plants and Lipman and MacKinney (6) showed that barley was unable to produce seeds if copper was entirely absent from the nutrient solution.

Copper occurs widely in soils. It is rarely found to be deficient in mineral soils, but on highly organic soils many cases have been reported where a notable improvement in the growth and yield of crops has been brought about through the use of copper sulphate. On the latter type of soil, considerable quantities can be added safely, but on mineral soils. excess of this salt may cause injurious results. In certain areas, both in Europe and the United States, the use of copper sulphate on muck or peat soils has proved necessary to the satisfactory growth of crops. Perhaps the most outstanding case is on the saw grass peat lands of the Florida Everglades, where the use of copper salts is considered indispensable.

Copper may be applied also in the form of plant sprays such as Bordeaux mixture. Chlorotic conditions of pear trees in South Africa and citrus trees in Florida have been reduced by spraying with a solution of a copper salt.

Zinc

Mazé (7) first indicated that zinc was necessary for plant growth. This was confirmed later by Sommers and Lipman (8) who used specially purified salts as nutrients. They showed that zinc was indispensable in five different plant families.

A deficiency of zinc is usually indicated by certain plant disorders and it is in the correction of these that zinc salts find their chief agricultural use. Bronzing of tung oil trees has been cured by applications of zinc salts and rosette or little leaf, a disease of pecan and citrus trees in southwestern United States, has been controlled by treatment with zinc sulphate applied to the soil, injected into the tree trunk or as a spray. A similar trouble in fruit trees in South Africa has also been corrected by using zinc salts.

Boron

Boron was shown by Mazé to be an essential element in the growth of maize previous to 1918. In 1923, Warington (9) at Rothamsted showed that broad beans could not be grown satisfactorily when boron was carefully excluded from the nutrient supply. Since that time a number of

workers have demonstrated the essential nature of boron as a nutrient for many different plants.

The amount of boron required by plants is very small; larger amounts than a few parts in the nutrient solution per million prove toxic to the plant. In California certain irrigation waters carry sufficient boron in solution to cause definite toxic effects to fruit trees. There have also been instances in which the boron impurities in commercial fertilizers, *e.g.*, muriate of potash, have been large enough to cause serious injury to the crop.

While it is probable that soils contain, as a rule, sufficient available boron to produce normal growth of most plants, there are an appreciable number of instances in which a boron deficiency has been proved to be the cause of or related to plant disorders.

Symptoms of boron deficiency vary somewhat with different plants, but usually new growth is interfered with and the leaves become affected. The transportation of carbohydrates within the plants appears to be prevented. In leguminous plants, the proper development of the nodule system rarely takes place in the absence of boron and less nitrogen is fixed. Some evidence has been brought forth to indicate that there is a relationship between the assimilation of calcium and boron in plants, though no definite proof of this has so far been presented.

Plant disorders attributed to a boron deficiency of the soil have become prominent during the past few years. Brandenburg and Meyer-Hermann (10) in Germany used borax successfully to combat crown rot of sugar beets and the results of this work have since been corroborated by trials in other European countries. Brown heart of turnips, known in different countries by various names, has been controlled with varying degrees of success by applications of small amounts of boron to the soil or by spraying the plants with a weak solution containing boron.

During the last three years a large number of field and laboratory experiments has been conducted in Canada by officials of the Dominion Experimental Farms, to study the effect on plant growth of boron applied to the soil and to the plant by spraying or, in the case of trees, by placing the boron compound in holes bored into the trunk.

Hill and Grant (11) give the following summary of their work with turnips:

"Employing pot sand cultures boron deficiency was characterized by a marginal yellowing of the foliage followed by a purpling and scorching. Roots were small and shrivelled or rotted at their juncture with the top. Supplying 0.25, 0.50, 1.0 and 1.50 ppm. of boron in the culture solution caused a progressive decrease of foliage injury. An inverse relationship was found between the amount of boron supplied and the occurrence of hollow heart of the roots. An inverse relationship was found between the amount of boron fed and the percentage ash in dry matter of the roots. A direct relationship was found between the amount of boron fed and the amount of boron found in the roots."

The Physiological Disorders Committee (12), Dominion Experimental Station, Summerland, B.C., in 1935 report control of drought spot and corky core of apples by injections of boron compounds into the trunk of the trees.

Perhaps the most extensive work with boron has been that conducted by the Maritime Brown Heart Committee to study the causes of the occurrence of brown heart in turnips. This committee has accumulated a large amount of data from field trials conducted at various points in the Maritime Provinces. The results of this work clearly showed that an application of from 1 to 2 pounds of boron (10 to 20 pounds of borax) per acre materially lessened the susceptibility of the turnip crop to brown heart and in many instances almost complete control was obtained. Of various carriers of boron, sodium tetraborate (borax) appeared to be the most satisfactory. As a result of these field trials, more comprehensive tests have been commenced at the branch experimental stations at Fredericton, N.B., Charlottetown, P.E.I., and Kentville, N.S., to study the residual and durational effects of boron applied at different rates to various crops.

Within the last year, the Division of Chemistry of the Central Experimental Farm, Ottawa, has devoted considerable time to a study of methods to determine the boron content of soils and plant material. Since chemical methods for determining small quantities of boron have not proved sufficiently sensitive, spectrographic methods have been investigated and Giles and Dyck of this Division have recently developed the following method which appears to be very satisfactory for the determination of water soluble boron in soils.

METHOD FOR THE SPECTROGRAPHIC DETERMINATION OF WATER-SOLUBLE BORON IN SOILS[3]

Ten gram samples of air-dried soil (2 mm. sieve) are weighed into 200 cc. silica dishes, 30 cc. boiling water added and allowed to stand not less than 40 minutes with occasional stirring. Filter through a Buchner funnel into 200 cc. silica dishes washing seven times with 20 cc. portions of boiling water. The filtrate is made alkaline with KOH solution (made up in a silica or platinum dish) and evaporated to dryness on a hot plate. Dissolve the dry residue in 8 cc. of phosphoric acid, keeping the dish in a desiccator during solution. Transfer to a silica distilling flask, rinsing the dish three times with 6 cc. portions of absolute methyl alcohol.

The methyl ester of boric acid formed under these conditions is distilled into a silica dish containing 15 cc. of water made strongly basic by keeping the latter beside an open beaker of concentrated ammonia under a bell jar for a few minutes. When no more methyl alcohol comes off, the solution in the distilling flask is allowed to cool, then 15 cc. more of methyl alcohol added and again distilled.

The methyl alcohol solution is then evaporated to about 10 cc. on a hot plate (at low heat). Fifty milligrams of pure calcium hydroxide and 0.025 mg. iron (as ferric chloride solution) are added and evaporated to dryness. The residue is well mixed with a spatula and 5 mg. portions are weighed and pressed into pellets. Standard pellets, containing known amounts of boron are prepared in the same manner.

The pellets are placed between the copper electrodes (spaced 2 mm. apart) of a large Helger Quartz Spectrograph adjusted to take the spectrum between the wave lengths 3300 and 3100 angstrom units and the arc spectrum is photographed at 3-minute exposures. In all determinations,

[3] Developed by the Division of Chemistry, Central Experimental Farm, Ottawa.

a constant amperage of $4\frac{1}{2}$ and voltage of 220 is maintained and a 15-second arcing precedes introduction of pellet.

When, in spectrograms of the standard pellets, the intensities at different concentrations of the boron line 2497.73 are compared (best determined by lantern projection) to intensities of the four iron lines 2501, 2510, 2518 and 2522 the following relations hold:

Intensity of Boron Line 2497.7

— with	0.00005	mgs. B. in pellet	=	$\frac{1}{2}$ intensity of Fe line 2518
— with	.0001	mgs. B. in pellet	=	intensity of Fe line 2518
— with	.0002	mgs. B. in pellet	=	intensity of Fe line 2501
— with	.0004	mgs. B. in pellet	=	intensity of Fe line 2510
— with	.0008	mgs. B. in pellet	=	intensity of Fe line 2522

The soil pellets are arced in triplicate and the intensity of the boron lines matched with one of the iron lines. For example, if of equal intensity to the 2510 iron line the pellet contains 0.0004 milligrams of boron and this figure by 1000 represents water-soluble boron in milligrams per kilogram or p.p.m. of soil.

A number of soil samples from different locations have been examined for water soluble boron content. Samples collected from areas where trials with boron for the control of brown heart in turnips were conducted showed a soluble boron content ranging from 0.2 to 0.8 p.p.m. On comparing the boron content of the soil with the occurrence of brown heart it was found that severity of the disease appeared to be associated with a low p.p.m. content of soluble boron in the soil. Samples collected at Ottawa from mangel and turnip areas which have not given indications of physiological disorders of the crops showed a soluble boron content ranging from 0.8 to 1.4 p.p.m., the latter figure being obtained from manured soil. The results of this analytical work are given in Table 1.

The large number of references to investigations dealing with the relation of minor elements to plant growth and prevention of physiological disorders indicates the increasing attention which has been given recently to this subject. It would appear that under certain soil and climatic conditions the application of small amounts of one or other of the minor elements, such as boron, manganese, copper, etc., is necessary if maximum yields and satisfactory quality of certain crops are to be obtained. As an example of the beneficial effect of boron on the mangel crop, the results of experimental work with minor elements at the Dominion Experimental Station, Kentville, N.S., are herewith briefly reviewed. This work was conducted under the supervison of Dr. W. S. Blair, Superintendent, in co-operation with the Division of Chemistry.

EXPERIMENTAL WORK WITH TRACE ELEMENTS AT THE DOMINION EXPERIMENTAL STATION, KENTVILLE, N.S.

An experiment was commenced in 1914 to study the effect of ground limestone used alone and in conjunction with commercial fertilizers. The plan also permitted a comparison of nitrate of soda and sulphate of ammonia as sources of nitrogen and superphosphate; basic slag and bone meal as sources of phosphoric acid—a total of six treatments (including a check) laid down in duplicate on four ranges of plots, the latter being 1/20 acre

TABLE 1.—ANALYSIS OF SOILS AND PHYSIOLOGICAL BREAKDOWN OF ROOT CROPS

Sample No.	Location	Crop	Occurrence of severe breakdown		pH value	Exchangeable		Soluble boron content
			No boron applied	Borax at 15 lbs. /acre		CaO	MgO	
			p.c.	p.c.		p.p.m.	p.p.m.	p.p.m.
1	Kentville, N.S. (Average 6 limed plots)	Mangels	100	0	6.2	1700—	35	0.24
2	Bathurst, N.B. (limed)	Turnips	100	11	7.0	3770	20	.60
3	Musquodoboit, N.S.	Turnips	93	2	6.1	1200	150	.40
4	Fredericton, N.B.	Turnips	91	13	6.2	840	130	.50
5	Black River Bridge, N.B.	Turnips	60	7	5.5	—	—	.40
6	Harvey, N.B.	Turnips	46	14	5.4	—	—	.70
7	Mouth of Keswick, N.B.	Turnips	43	5	5.6	—	—	.80
8	Iona, P.E.I.	Turnips	37	33	6.5	1680	40	.50
9	West Bathurst, N.B.	Turnips	35	12	5.6	—	—	.80
10	Bathurst, N.B. (no lime)	Turnips	15	7	5.6	1770	140	.80
11	New London, P.E.I.	Turnips	14	21	6.2	2070	100	.60
12	Lunenburg, N.S.	Turnips	2	2	6.6	1390	210	.80
13	Kentville, N.S. (Average 6 unlimed plots)	Mangels	Slight	Nil	5.1	640	62	.20
14	Ottawa (manured soil)	Mangels	Nil	Nil	—	—	—	1.40
15	Ottawa (basic slag)	Turnips	Nil	Nil	—	—	—	.80
16	Ottawa	Turnips	Nil	Nil	—	—	—	.90

in area. The soil of the area was a gravelly, sandy loam, low in fertility and quite strongly acid.

The rotation from 1914 to 1925 was potatoes, grain and clover hay. The fertilizers were applied every three years for the potato crop. In fertilizing constituents, the materials applied equalled an application of 500 pounds of 4-9-10 per acre. In 1917 the whole area was dressed with manure at 15 tons per acre, but no manure has been applied since that date. The lime treatment consisted of an application of 2 tons of ground limestone in 1914, 1917, 1920 and 1924 on the two centre ranges of plots—in all a total of 8 tons per acre during the period 1914–1925.

Owing to the severe development of potato scab on the limed ranges, it was decided to substitute mangels for potatoes as the hoed crop in 1926. Further, as the yields had been consistently low except for the rotation in which manure had been applied in 1917, the application of fertilizers was increased in 1926 and from that date the equivalent of 1600 pounds of a 4-9-6 mixture has been applied for the hoed crop. No limestone has been applied since 1924.

The yields from this experimental area have been lower than those which might be expected following the application of 1600 pounds of a 4-9-6 fertilizer mixture every three years for the hoed crop. Those from treatment No. 1, which received 420 pounds of nitrate of soda, 450 pounds of 16% superphosphate, 450 pounds of 16% basic slag and 202 pounds of muriate of potash per acre, are given in Table 2 for the period 1926–1935.

Table 2.—Yields per acre from Treatment No. 1 of Experiment V, Kentville, N.S. 1926–1935

Year	Mangels		Wheat		Clover hay	
	Unlimed	limed	Unlimed	Limed	Unlimed	Limed
	bush.	bush.	bush.	bush.	tons	tons
1926	373.2	570.0				
1927			17.5	25.8		
1928					0.81	1.92
1929	462.8	466.0				
1930			9.2	13.2		
1931					0.82	1.68
1932	421.3	633.0				
1933			13.6	15.5		
1934					1.03	1.03
1935	203.6	292.0				
Average	365.2	490.3	13.4	18.2	0.89	1.54

In each of the mangel crops the plants were affected by a physiological disorder or disease similar to crown rot of sugar beets. The first symptom noticed was an unnatural curling of the leaves followed by browning or blackening of portions of the edges of the leaves and frequently by a discoloration of portions of the leaf stem. The leaves and stems of a large portion of the crop suffered so severely from this condition that they finally fell from the crown and then small secondary leaves commenced to grow from the crown of the plant. In 1929 the disease was so pronounced that crown rot developed on many of the mangels especially on the limed ranges

In the spring of 1935, it was decided to determine the effect of plant food elements, other than those furnished in the fertilizer mixture, on the occurrence of the breakdown. For this purpose six small plots of 1/240 acre were laid out at the end of each range and fertilized uniformly by applying broadcast the same materials as given in treatment 1 of the main area. The land in each case had been previously cropped, limed and fertilized similarly to the adjoining main plot ranges. On these small plots, the internal physiological breakdown had been present to the same extent as on the main plot area. The treatments were as follows:

Magnesium sulphate	at 120 pounds per acre
Sodium tetraborate	at 10 pounds per acre
Manganese sulphate	at 50 pounds per acre
Copper sulphate	at 15 pounds per acre
Zinc sulphate	at 15 pounds per acre
Manure	at 15 tons per acre

With the exception of the manured plot, the above materials were applied on top of the row and worked in well with a hand rake before seeding the mangels with a garden drill. Each plot contained six rows thirty inches apart and twelve feet long. In most cases, symptoms of the disorder became apparent during the summer and more particularly on the limed ranges. The disorder, however, did not attack the crown of the mangels. The yields per acre and occurrence of disease are given in Table 3.

TABLE 3.—AVERAGE OF DUPLICATE YIELDS OF MANGELS PER ACRE—SMALL PLOTS OF EXPERIMENT V—KENTVILLE, N.S.—1935

Treatment per acre (in addition to 1600 lbs. of 4-9-6)	No. of plants per plot		Average weight per plant		Per cent of plants affected		Yields per acre	
	Un-limed plot	Limed plot	Un-limed plot	Limed plot	Un-limed plot	Limed plot	Un-limed plot	Limed plot
			lb.	lb.			bush.	bush.
Magnesium sulphate—120 lbs.	75	75	0.86	0.78	17	100	298.	281
Sodium tetraborate—10 lbs.	73	86	1.17	2.24	Nil	Nil	409.	927
Manganese sulphate—50 lbs.	64	74	0.95	0.72	21	100	293.	257
Copper sulphate—15 lbs.	52	60	0.79	0.89	56	100	201.	257
Zinc sulphate—15 lbs.	42	74	0.58	0.75	20	100	116.	264
Manure—30,000 lbs.	72	91	0.84	0.66	11	100	295.	288
Fertilizer only (Plot I) Exp. V.	Fair stand	Good stand				100	204.	292
Unfertilized plot	Nil	V. poor stand				100	No crop	11

This experiment was of a preliminary character and the area available did not permit of sufficient replication for satisfactory subjection of the results to statistical analysis. However, the results from the application of ten pounds of borax per acre may be considered as being quite significant.

The boron treatment completely controlled the occurrence of the disease on both limed and unlimed ranges and increased the yield 217% and 100% respectively over the plot which did not receive boron and was otherwise treated the same.

The application of manganese, copper, zinc and magnesium apparently did not have any beneficial influence on yield on the plots originally limed. On the unlimed plots the treatment with magnesium, manganese and manure appears to have been of some benefit, but further work to corroborate such a deduction is necessary. There are indications that the application of zinc on the unlimed plots may have had a depressing effect on growth since the stand and yields from this treatment are markedly below those of the other plots.

It may be noteworthy that disease infection on the originally limed range of plots not treated with boron averaged 100% while on the unlimed it averaged only 25%. This indicated that the availability of the boron of the soil of the former might be considerably less than that of the latter plots. Examination of soil samples collected in 1932 from the plots of Experiment V have not shown this to be the case. The average soluble boron content of the soil of the unlimed plots (having a pH of 5.1) was found to be 0.20 p.p.m. and of the limed plots (pH 6.2) it was 0.24 p.p.m. Apparently in both cases this soluble boron content was too low to permit of normal development of the mangel plant.

From the data given in this paper, it may be concluded that a sufficient quantity of the element boron in an available form in the soil is necessary for the healthy growth of mangels, turnips and apples. It would appear very desirable that further studies of the boron content of soils, of rates and methods of applying this element for the above crops and the effect of such treatment on subsequent crops, be conducted.

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MAGNESIUM IN FIELD CROP PRODUCTION IN NEW BRUNSWICK[1]

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In recent years numerous farmers in various sections of Saint John River Valley area of New Brunswick have suffered considerable reduction in their potato and grain crops, the result of a condition which up until three years ago was the cause of considerable concern to those interested.

After providing good seed, good cultivation and ample fertility as ordinarily understood, grain crops would turn yellow shortly after coming up and produce a slow growth and a reduced yield.

FIGURE 1. Potato foliage showing symptoms of magnesium deficiency.

Potatoes in July developed in many instances a chlorotic, unhealthy appearing condition. Thickening, wrinkling, rolling and brittleness of the leaves was characteristic and dead areas finally appeared and the whole leaf in severe cases turned brown, died and fell off. In mild cases only the lower leaves were affected, while in severe cases all of the older leaves were

[1] Read before a joint session of the Soils Group of the C.S.T.A. and the Canadian Phytopathological Society at the University of New Brunswick, Fredericton, N.B., July 14–15, 1936.
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affected and only the new growth was functional. The result was an early death of the crop and consequent reduction in yield. The cause of this was variously interpreted as a result of disease, lack of drainage, excess of rainfall and drought. This condition reached such proportions in the potato growing sections of the area specified that a careful investigation of the condition referred to was undertaken in 1933, which investigation is continuing at the present time.

A series of soil samples taken from potato fields variously located in the Province were tested for available nitrates, ammonia, phosphoric acid, potash, calcium, magnesium, manganese, iron, aluminum and sulphates in accordance with the method outlined by Spurway (1). This investigation indicated regional areas with low available magnesium as shown in Table 1, which areas in turn were associated with the crop condition referred to.

This survey was followed in the summer of 1934 by a series of field tests with applications of magnesium sulphate to the soil, and as a spray

TABLE 1

County	Number of samples	Per cent showing high and medium available magnesium	Per cent showing low and very low available magnesium
Madawaska	8	27.5	62.5
Victoria	102	24.4	75.6
Carleton	101	39.5	60.5
York	44	34.0	66
Saint John	12	66.6	33.4
Westmorland	15	86.5	13.5
Northumberland	1	100	0
Gloucester	6	100	0
Restigouche	16	50	50

TABLE 2

Location	Increase per acre from magnesium sulphate	Decrease per acre from magnesium sulphate
	Bbls.	Bbls.
Grand Falls	15	
Grand Falls (spray application)	54	
Plaster Rock	25	
Plaster Rock	20	
Bath	8	
Mouth Keswick	19	
Dorn Ridge	28	
Dorn Ridge	7	
Long Reach (spray application)	69	
Centreville	24	
Centreville	15	
Pinder	20	
Hartland	40	
Andover	25	
Burton (spray application)	7.5	
Millville	62.0	
Florenceville		
South Tilley		25
Oromocto		13
Centreville		54
New Denmark	0	0
North View	0	0

at rates varying from 60 to 100 lbs. per acre. The results with potatoes in most instances was a healthier growth and an increase in yield as shown in Table 2.

In three trials with oats a favourable response was noted in two instances and no response in the third. A threshing test on one of the improved fields showed a yield of 20 bushels of oats per acre from the untreated area as compared to 44 bushels per acre from the treated area. The increased yield was reflected in the early period of growth by the healthy appearance of the crop as judged by color and vigor.

FIGURE 2. Effect of application of magnesium on oats. Left: Untreated; Right: treated.

In two trials with wheat an improvement in color and vigor of growth was noted in one instance while no improvement was noted in the other.

One trial with corn and beans respectively showed a favorable response. A trial with cucumbers resulted in an increase in the vine growth where magnesium sulphate was applied.

The results of these field experiments were checked against the soil tests and it was found that a very high degree of correlation existed between the laboratory test for available magnesium and the field response. From the results obtained it seemed apparent that the physiological condition referred to was related to magnesium.

This work was followed up in 1934 by a survey of the province to determine the frequency of a possible magnesium deficiency of the soil as reflected and interpreted from growing crops, particularly oats and other grains. These observations were checked with laboratory tests for available magnesium by the method outlined by Morgan (2). Symptoms of the physiological condition in crops apparently related to available magnesium in soils were very few outside of the potato growing sections. Within the potato growing sections the symptoms were more apparent.

The results of the test for available magnesium in the areas under observation are shown in Table 3. A high degree of correlation was found to exist between field observations and soil tests for available magnesium particularly in Victoria, Carleton, York, Queens, Sunbury, Kings and Restigouche Counties.

TABLE 3

County	Number of samples	Per cent showing high and medium available magnesium	Per cent showing low and very low available magnesium
Victoria	6	—	100
Carleton	15	—	100
York	5	—	100
Queens-Sunbury	14	60	40
Kings	8	12.5	87.5
Albert	4	75	25
Westmorland	12	33.3	66.6
Kent	17	53	47
Gloucester	4	100	
Restigouche	22	45.5	54.5

In 1935 the study of this problem was continued by the survey method on the basis of laboratory determinations (Morgan, 2) of available magnesium in each field on a group of farms in Carleton and Victoria Counties.

A wide range of available magnesium was noted on individual fields on several farms. Results are shown in Table 4.

TABLE 4

County	Available magnesium per acre, lbs.											
Field No.	1	2	3	4	5	6	7	8	9	10	11	12
Carleton Farm No. 1	25	35	25	25	25	50	25					
Carleton Farm No. 2	40	40	25									
Carleton Farm No. 3	10	200	10	25	50	25	150					
Carleton Farm No. 4	40	40	5	65								
Carleton Farm No. 5	40	25	10	10	25	60	50					
Carleton Farm No. 6	10	25	15	10	0	5	35	50	25	60		
Carleton Farm No. 7	90	40	125	50	5	5	5	25	100	5	5	5
Victoria Farm No. 8	5	40	75	10								
Victoria Farm No. 9	0	15	100	10	35	60						
Victoria Farm No. 10	10	0	150									
Victoria Farm No. 11	10	10	—	25	25	25	25	25	5	40	25	
Victoria Farm No. 12	60	30	70	10	25	25	45	10	25	40		

DISCUSSION

A physiological condition affecting crops in New Brunswick has been corrected by applications of magnesium compounds such as magnesium sulphate and magnesium carbonate to the soil.

Field observations and soil tests indicate that the occurrence of low available magnesium in the soil is most frequent in the specialized potato growing sections of the Province. The theory was advanced in the early stage of this investigation that heavy applications of commercial fertilizer by potato growers was possibly responsible for a loss of basic elements in the soil when associated with extensive cultivation, crop removal and leaching.

Results obtained at some United States experiment stations with lysometer experiments indicate that gypsum speeds up the leaching of magnesium. Heavy applications of gypsum naturally occur with the use of superphosphate, and repeated applications together with intensive cultivation have possibly resulted in speeding up losses of available magnesium from the soils in the potato growing sections of the Province. Analyses of the drainage waters of the Saint John River in flood season show heavy magnesium leaching.

It has been determined that potatoes showing the physiological condition referred to can be restored to normal growth in a week or ten days following a spray application of magnesium sulphate. Potato yields were increased 69 bbls. per acre in one carefully conducted experiment from a spray application made on July 2nd. Spray applications have been made as late as July 30th with satisfactory results.

The rapid chemical tests recently outlined by Morgan and Spurway in respect to available magnesium determinations have been of considerable assistance in this investigation and have shown a good correlation between field observations and soil treatment in respect to magnesium.

It is probable that the problem in its widest sense is concerned with the minimum amount of available soil magnesium necessary for the complete rôle of this element, both external and internal to the plant rather than an actual deficiency of the element for chlorophyll manufacture. However certain cases where benefit was derived from spray applications of magnesium salts would seem to indicate that there was an insufficiency of magnesium for normal chlorophyll development and function. An unconcluded study of the mineral content of young grain showing the physiological symptoms referred to indicates a low phosphoric acid content as well as a low magnesium content in the ash. An examination of the roots of affected grain crops shows a marked restriction or degeneration of the root system, which possibly might be related to the availability of phosphoric acid.

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Résumé

Le magnésium dans la production des récoltes de grande culture au Nouveau-Brunswick. E. M. Taylor, Ministère de l'Agriculture, Fredericton, N.-B., et J. L. Howatt, Station expérimentale fédérale de Fredericton, N.-B.

Dans les régions de la Province du Nouveau-Brunswick, où la pomme de terre est l'objet d'une grande culture, cette récolte, de même que les céréales, a souffert de troubles physiologiques, et l'expérience a démontré que ces désordres sont dus à un manque de magnésium dans le sol. Les applications à la terre ou aux plantes respectivement de sulfate de magnésium ou de carbonate de magnésium, sous forme sèche ou en solution, ont prévenu ces désordres, et il en est résulté des augmentations de rendement qui ont atteint jusqu'à 69 barils à l'acre pour les pommes de terre et 24 boisseaux à l'acre pour l'avoine.

PROGRESS REPORT ON THE INVESTIGATION OF BROWN HEART OF SWEDE TURNIPS AT MACDONALD COLLEGE[1]

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Co-operative studies between the departments of Plant Pathology and Agronomy on the brown heart of swede turnips were begun in 1932, when for the first time at Macdonald College the trouble was observed to be of real importance. Extensive field and greenhouse experiments have been conducted during the past five years in an effort to discover the nature, cause, conditions of development, and control of the disease. Only a brief résumé of the results obtained to date is presented in this article, but a much more comprehensive paper will be published shortly. Our findings substantiate the view that brown heart is a boron deficiency disease which can be controlled by the application of suitable amounts of borax to the soil, as has been reported by MacLeod and Howatt (2), O'Brien and Dennis (3 and 4), Whitehead (5), and others.

The term brown heart has become quite generally used to designate greyish-brown or dark-brown portions of diseased tissues, which appear water-soaked and which occur only or mainly in the lower part (root portion) of the fleshy "roots" or "bulbs" of swedes. In cross-sections the disease appears as discoloured areas of various sizes and shapes, the arrangement of which may be imperfectly concentric, somewhat radial, or merely scattered. The total area involved may vary from a single small patch or arc of tissue to as much as three-quarters of the whole "root". A peripheral zone including the cambium seems always to remain healthy under field conditions, even though the plant is very severely affected. In advanced stages the diseased tissues tend to collapse, forming cavities. Thus at times the "bulb" becomes a mere shell of healthy tissues enclosing a single large cavity. Reference to Figure 3 will give some idea of the nature and distribution of the diseased areas.

Usually under field conditions no external symptoms are associated with brown heart; when plants are grown in the greenhouse either in soil or sand culture, the appearance of the skin is sufficient to indicate the presence of brown heart. A healthy "root" has a smooth skin while a diseased one has a rough, scurfy, or cracked surface, particularly on the upper parts. The severity of brown heart under these conditions is directly correlated with the degree of skin roughness. Occasionally in the field, severe brown heart can be detected by the roughness of the skin. However, the usual absence of reliable external field symptoms necessitates the cutting of large numbers of "roots" in order to determine the presence and severity of the disease in the crop.

Brown heart does not increase or decrease in storage, but in time the discoloration largely disappears and the diseased tissues become greyish and punky and less strongly differentiated from the surrounding healthy tissues. The affected plants are particularly subject to rots both in the field and in storage.

[1] A short form of a paper given before a joint session of the Horticultural Group and the Soils Group of the Canadian Society of Technical Agriculturists, and the Canadian Phytopathological Society, at the University of New Brunswick, Fredericton, N.B., July 15, 1936. Contribution from the Faculty of Agriculture of McGill University, Macdonald College, P.Q., Canada, Journal Series No. 83.
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A number of investigators who have studied the effects of subminimal supplies of boron upon various species of plants have found that one of the most common and earliest-appearing symptoms of a boron deficiency is the death of the tissues of the growing points (buds) and regions resulting in reduced growth and yields. Trouble in these parts has never been found associated with brown heart under field conditions, and applications of borax giving control of brown heart have not resulted in improved yields.

Greenhouse studies have included both soil and pure-sand culture tests (Figure 1). Both types of trials have given valuable results; but the latter, in which various amounts of boron have been supplied in the nutrient solution, have been particularly instructive and have shown conclusively that brown heart is due to a boron deficiency. Nutrient solutions containing the following concentrations of boron as boric acid have been used: 0, 0.25 p.p.m., 0.50 p.p.m., 1 p.p.m., 2 p.p.m., 5 p.p.m., 25 p.p.m., 50 p.p.m., and 100 p.p.m. With no boron added to the nutrient solution, the plants grew normally for six to eight weeks and then developed yellowish, mottled, distorted leaves, and eventually died without forming a bulbous "root"; with 0.25 p.p.m., there developed purpling of the leaf margins and undersurfaces, curling, ruffling, yellowing, and mottling of the leaf blades, galling and splitting of the petioles, midribs, and veins, extremely rough skin and reduction of size of the "roots", and very severe brown heart accompanied by some disintegration of the cambium; with 0.5 p.p.m., the foliage and size of plant was normal, the skin showed distinct roughness, and brown heart was severe, but the cambium was healthy; with 1 p.p.m., the plants showed no external symptoms, and brown heart was extremely slight; with 2 p.p.m., and higher concentrations no brown heart occurred (See Figures 3 and 4); toxicity as indicated by yellowing and death of leaf margins and reduction in size of plant began to show at 25 p.p.m. and increased progressively with the higher amounts, but even with 100 p.p.m. plant development was quite good, showing that the swede has a high degree of tolerance to this element. These results are, in general, in accord with those reported by Hill and Grant (1).

The course of development of brown heart has varied somewhat from year to year. However, roots planted about the middle of May have shown the first signs of disease in the latter part of July, and became progressively more affected until late in October. Late as compared to early planting has reduced the trouble. This agrees closely with data from other experiments, which show a direct correlation between size of "root" and percentage and severity of brown heart. Young or old plants two inches or less across rarely develop the trouble.

The amount of brown heart has varied a great deal from year to year in the same field. In one selfed-line used extensively in these studies, the amount has shown a maximum variation from 38% to 80% during the five-year period. A similarly wide variation has occurred when the same variety has been grown in the same year in different fields on the College farm, even though the fields appear to be of the same soil type and have been subjected to the same cultural practices for a number of years. In general, light soils have given more trouble than heavy soils. Varietal susceptibility has been studied in a number of commercial varieties and a large group of selfed-line strains. The figures for these tests range from 11 to

FIGURE 1. General view of soil and sand culture tests in greenhouse, 1936. Note that growth of plants is much more vigorous in sand cultures (rear bench) than the growth in soil (front bench). Plants all of the same age.

FIGURE 2. Sand cultures, 1935. Left—basic nutrient; centre—basic nutrient plus manganese; right—basic nutrient plus manganese plus boron 2 p.p.m.

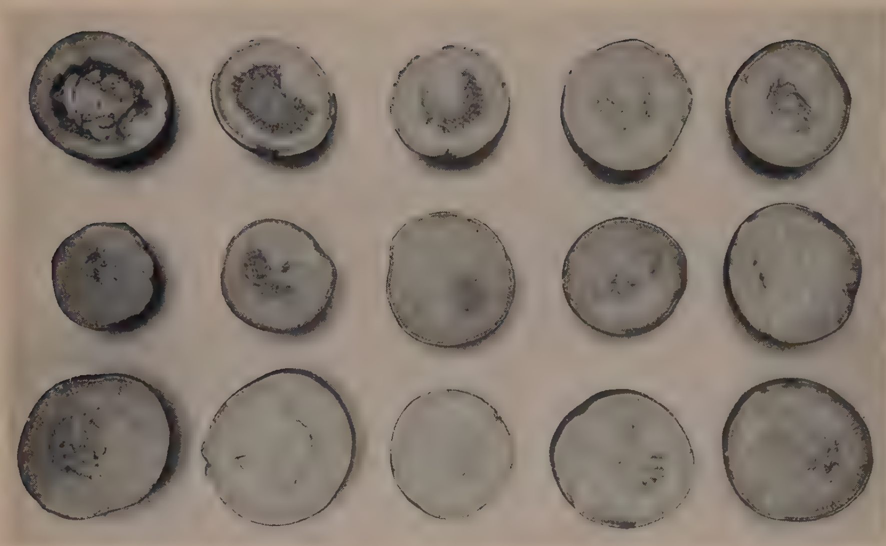

FIGURE 3. Swedes photographed in cross-section to show variation in degree and distribution of brown heart.

FIGURE 4. Swedes grown in sand cultures—left, in nutrient with 0·5 p.p.m. boron, brown heart definite; centre, in nutrient with 1 p.p.m. boron, slightly diseased; right, in nutrient with 2 p.p.m. boron, no brown heart—note size unaffected.

73% brown heart; while some varieties are markedly resistant, complete resistance has not appeared.

An excellent opportunity has been afforded to check the effect of the use of manure against mineral fertilizer. A piece of land involved in a farm-rotation experiment which had been running for many years provided an area which had been fertilized continuously with manure alone, another fertilized with mineral fertilizer alone, and a third had received a combination of the two. Each had been treated in the same way since 1912. The average brown heart occurrence for the three years 1932, 1933, and 1934 for each area was as follows: manure alone 72%; manure plus mineral fertilizer 89%; and fertilizer alone 99%. In 1932 the mineral fertilizer alone gave 100%, while the manure alone gave only 60% brown heart.

Brown heart has been much reduced by maintaining the soil moisture high by means of irrigation. In greenhouse trials, increasing the acidity of the soil with hydrochloric acid from pH 6.1 to 5.2 almost completely eliminated the disease, while raising the pH of the same soil to 7.2 with either sodium hydroxide or lime increased very markedly its severity.

In field tests in 1935 on control, applications of 25 pounds and 50 pounds of borax to the acre gave satisfactory results. In one test, the check plots averaged 46.67% brown heart, the plots with the 25 pounds per acre application 14.22%, and the plots treated with 50 pounds per acre 5.78%. Both rates were applied at three times, *viz.*, just before seeding, after thinning, and toward the end of July when brown heart was just beginning to appear in adjacent plots of the same variety. Each rate of the first application was made in two ways, broadcast and as a band on either side of each row. For the last two applications the borax was dissolved in water, making a 2% solution, and applied in the required amounts, in one series of plots to the soil on either side of each row and in another series as a spray to the foliage. These various times and methods of application gave no significant differences in control.

In tests in the same field in 1934, rates of 20 pounds or less per acre gave no control. The relatively high amounts of borax required to effect control on the College farm is probably due to the fact that the soil is a calcareous one (pH 6.5 to 6.9), since it has been shown that lime may increase this trouble.

While marked progress has been made towards a solution of this problem, there are a number of phases which need to be more fully investigated. For example, little if anything is known concerning the physiological rôle and distribution of boron in the plant, and factors determining its availability in the soil. From the practical standpoint, definite information is needed relative to the effects of boron on other farm crops before its use can be safely recommended.

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THE USE OF THE ANALYSIS OF VARIANCE IN SOIL AND FERTILIZER EXPERIMENTS WITH PARTICULAR REFERENCE TO INTERACTIONS[1]

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Very great advances have been made in the technique of field experimentation since the beginning of the present century. About 1908 a beginning was made in the application of statistical methods to the study of plot variability and to the interpretation of results of field experiments on a moderate scale. Since then a great deal of work has been done on such matters as size and shape of plots, frequency of replication, methods and frequency of using check plots, border effect, competition, sampling methods, etc. As a result of this work considerable improvement has been made in experimental technique. More recently the work of Dr. R. A. Fisher and his co-workers has raised field experimental methods to a much higher plane through the development of the "analysis of variance", and through emphasis on the "design of experiments". In spite of this, statistical methods are not well understood, and, therefore, are not used as they should be in many cases.

In all experiments in which field soils are involved there is great variation in the results obtained, no matter how much care is taken to have the conditions uniform. Many fields which have been considered to be good for experimental purposes have been found to vary to such an extent, when uniform crops have been grown on them, that with single plots differences from the mean of 20, 30, and sometimes even 50% have been observed.

When one obtains differences of this size in studying treatments of any kind, it means that he cannot be sure that they are not due to variation in the soil rather than to the effect of the treatments. For this reason it is necessary to have some means of measuring the normal variation that is associated with an experiment, so that it can be determined whether any treatments being compared differ sufficiently to warrant the conclusion that they are significantly different.

There are several possible ways of measuring variation. If we have a series of data from an experiment, it is an easy matter to determine the range, the average deviation, the standard error, and the probable error. Each of these measures is of use, but they are not equally valuable. It has been established that most quantitative data such as yield, height, and many others, follow closely the normal "curve of error", and since the "standard error" bears a constant relation to this curve, it has become almost universal to use it in examining the results to test their significance. The relationship is such that approximately 68.3% of the observations fall within the area of the curve determined by the mean "plus or minus" the "standard deviation", and 31.7% fall outside of those limits. Further, about 95% fall inside the mean plus or minus twice the standard error, and 5% fall outside. In other words, only once in about twenty times will an

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observation be obtained by chance that is outside plus or minus twice the standard error from the mean. If, as the result of an experiment, a difference of twice its standard error is obtained, since we know that this would occur by chance only once in twenty times, we can be fairly certain that it is a real difference.

Twice the standard error is conventionally taken as a measure of significance in many classes of work, and when this is done one will follow up a wrong conclusion only once in twenty times on the average. However, by using information that is available regarding the normal curve, we may calculate the difference required for any "degree of certainty" which we care to choose.

As mentioned previously, Dr. R. A. Fisher has been responsible for developing the analysis of variance. This has proven to be of immense value in examining and interpreting experimental results, and has brought out the need for proper planning of experiments to allow of the most satisfactory analysis being made. For the purpose of illustration, we present in Table 1 an analysis of variance of a simple experiment involving five varieties in fourfold replication, the several replications being placed on different blocks of land.

TABLE 1.—ANALYSIS OF VARIANCE OF A VARIETY EXPERIMENT

Source of Variation	Sum of Squares	D.F.	M. Sq. or Variance	$\frac{1}{2}\log_e$	z Value	
					Obtained	For P = .05
Varieties	305.22	4	76.30	2.17	1.21	0.59
Blocks	66.79	3	22.26	1.55	.59	.62
Remainder (or error)	82.28	12	6.86	.96		
Total	454	19				

Standard error = 2.6. Standard Error for a mean of 4 plots = 1.3.

The term "variance" is simply the "mean squared-deviation", or the "standard error squared". In an analysis of variance the total variation, as measured by the sum of the squares of all the deviations from the mean, is simply divided up into independent portions, *e.g.*, varieties, blocks and remainder; then by dividing each of the several sums of squares by the appropriate number of "degrees of freedom"[3] the several variances are obtained.

As to whether the contributions of the several sources of variation are significantly different from one another may be determined by appropriate comparisons of the variances. Fisher's method of doing this is by calculating one-half the natural logarithms of the several variances, and from these obtaining what are called the z values. The z value is merely the difference between the half logs of the two variances which are to be compared. Usually the important comparison is that between treatments and error, but in some cases other comparisons also may be important.

For convenient use Fisher has prepared a table giving the z values corresponding to P = 0.05 and P = 0.01 for comparing variances. A z value exceeding that for P = 0.05 is obtained by chance once in twenty

[3] By "degrees of freedom" is meant the number of values that can be set down arbitrarily.

trials, while one exceeding that for P = 0.01 is obtained by chance only once in one hundred trials. When the difference between two variances is such as to give a z value corresponding to P = 0.05 it is conventionally assumed that it is a real one and therefore significant. When a z value corresponding to P = 0.01 is obtained, it is considered to be highly significant. In using the z table it is necessary to take into account the degrees of freedom from which the determinations of the variances have been obtained, and to enter it with n_1 corresponding to the number of degrees of freedom of the larger variance.

In the above example, the z value for varieties (1.21) is shown to be greater than that given in the table for P = 0.05 (0.59). It is therefore concluded that the varieties did not all yield equally well. To go further and compare one variety with another, it is necessary to examine the differences in variety averages by means of the standard error methods in common use. The standard error of the experiment is obtained by extracting the square root of the variance for the remainder, for this represents the uncontrolled and unaccounted-for variation. In our experiment this is found to be 2.6 for a single plot, or 1.3 for a mean of four plots.

Having reviewed the meaning of the analysis of variance and its use in this simple experiment, it will be advantageous to present another one of a more complex experiment, in which interactions or differential effects are involved. With a view to determining which variety or varieties should be recommended, six varieties of wheat were carried in a comparative test at four farms, in each of three different years, and in each case the experiment was carried in four-fold replication. The design of the experiment is illustrated diagrammatically in Figure 1.

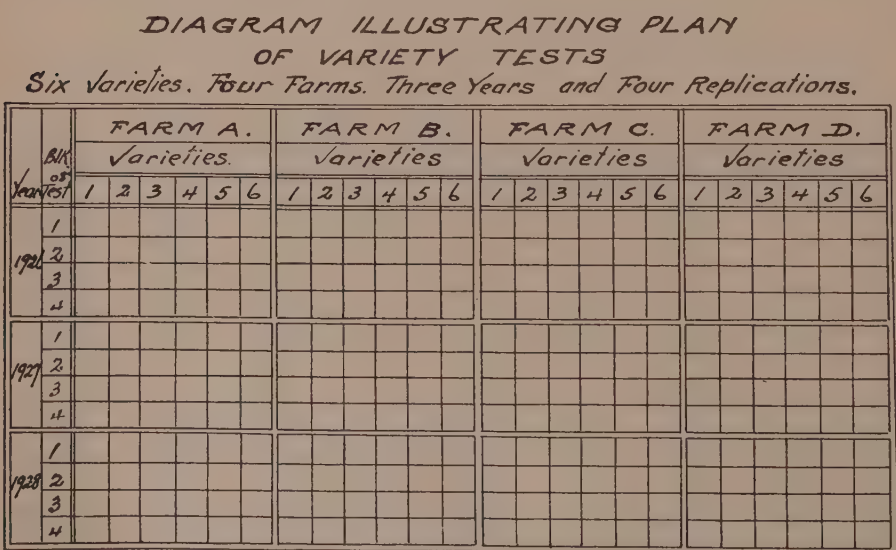


FIGURE 1

Such an experiment if properly carried out and if the error variance does not differ significantly from farm to farm or from year to year allows one to divide up the total sum of squares into nine different parts, and to calculate therefrom as before the corresponding variances. These are:

the simple effects of varieties, farms, years, and blocks; the interactions of varieties on years, varieties on farms, years on farms, and varieties on years on farms; and a remainder representing the unaccounted-for variation. The standard error of the experiment is calculated from the variance for remainder.

The analysis of variance for this experiment is presented in Table 2.

TABLE 2.—ANALYSIS OF VARIANCE OF AN EXPERIMENT INVOLVING SIX VARIETIES IN FOUR-FOLD REPLICATION CARRIED ON FOR THREE YEARS AT FOUR FARMS*

Sources of Variance	S.S.	D.F.	M. Sq. or Variance	$\frac{1}{2}\log_e$	z Value for comparing: Sources and Error		Varieties and Interactions	
					Obt'd.	P = .05	Obt'd.	P = .05
Simple Effects								
Years	216	2	108	2.34	1.57	0.54		
Farms	11,283	3	3761	4.11	3.34	.47		
Varieties	1,193	5	239	2.73	1.96	.39		
Blocks	1,334	36	37	1.80	1.03	.20		
Interactions								
Yrs. × Farms	3,737	6	623	3.21	2.44	.37	.86	0.60
Yrs. × Vars.	427	10	43	1.87	1.10	.33	1.23	.53
Farms × Vars.	302	15	20	1.50	.73	.28	.99	.46
Farms × Yrs. × Vars.	975	30	32	1.74	.97	.20		
Error	840	180	4.67	.77				
Total	20,308	287						

Standard error = 2.16

* Calculated from data obtained from the Dominion Experimental Farms at Cap Rouge, Lennoxville, Ste. Anne de la Pocatière, and from Macdonald College. The experiment was repeated on different soil at each farm each year.

In this table the *z* values obtained by comparing the error variance with those of the several other sources of variation are presented. As well there are given the *z* values obtained by comparing the variety variance with three of the interactions, with which, as will be seen, it may be important to compare them. In both cases the *z* values corresponding to P = .05 are included so as to allow for a test of significance. From this analysis the significance of the various treatment differences which the experiment furnishes can readily be obtained. It will be advantageous to discuss the interpretations which it allows.

As far as such an experiment is representative of the conditions for which an answer is desired, and using P = .05 as the test of significance, the following interpretation may be made:—

1. The wheat crop yielded differently in different years.
2. Some farms were better on the whole as producers of wheat than others.
3. Some varieties, generally, were better yielders than others.
4. The replication of the experiment in blocks made it possible to reduce the error variance and so increase the precision of the experiment.
5. The interaction of years and farms is quite significant; that is to say, wheat (average of all varieties) yielded relatively better on some farms

in some years than it did in others. However, varietal differences are not involved here, and so this has no relation to our recommendations regarding varieties.

6. The interaction of varieties and years is significant, or, put in other terms, some varieties did relatively better in some years and others did more poorly. Now, if the average differences between varieties (over all years) are not greater than this interaction of varieties and years, one cannot recommend any one variety for all years, for one does not know at seeding time what sort of a year is going to follow. In this instance, however, the variance for varieties is significantly greater than the interaction of varieties on years, and so some varieties may be recommended over others.
7. There is a significant interaction of varieties and farms. This means that some varieties did relatively better on some farms than on others. Again, if the variety effect had not turned out to be significantly greater than this interaction, it would mean that one could not recommend any variety generally, and that recommendations should be made for each farm separately. In our example, however, the situation is that there are some varieties which did well generally, yet some of them did relatively better on certain farms.
8. There is a significant second-order interaction of variety, years and farms. This means that the year-variety interactions were different on different farms. The variety effect is so much greater than this interaction, however, that one need not consider it. It may be said that second order interactions are usually small, although they sometimes may be important.

It should be pointed out that, after determining by an analysis of variance, which of the sources of variation have shown significant effects, it is desirable by the application of standard error methods to the appropriate tabulations of averages, to trace down in detail the various simple effects and interactions, and to determine where they occur. For example, one can determine which is the best farm for wheat in general, which is the best variety, on which farms the several varieties do best, etc. This matter has been fully discussed in another paper[3] and need not be dealt with further here.

It should be observed that varieties, in the above experiment, might have been replaced by fertilizer or cultural practices, or by any other kind of treatment. In a fertilizer experiment, for example, on account of different moisture and temperature conditions, we know that we may expect to get quite different responses in different years and also on different soils. If one is carrying on a test with a view to using the results as a basis for fertilizer recommendations, it is important to know not only which in general are the best fertilizer treatments, but also whether or not the relative response to fertilizer treatments is significantly different on different farms. In other words, it is important to know whether the simple effects are significantly greater than the interaction of fertilizers and farms. If they are not, then one cannot recommend any particular fertilizer treatment for any farm. Similarly, if the simple effects of fertilizer treatments are not significantly greater than the interaction of fertilizers and years, one cannot recommend any particular fertilizer treatment over any other,

[3] Immer, F. R., H. K. Hayes and L. Powers—Statistical Determination of Barley Varietal Adaptation A.S.A. 26 : 5. 1934.

for, as in the variety experiment mentioned previously, at the time of fertilizer application one does not know what sort of a year is going to follow.

For these reasons, if a fertilizer experiment, or any other experiment, is to be used as a basis for general recommendations, it should be carried out in such a way as to test not only whether the several simple effects of the treatments are significant, but also to test whether the several possible interactions are significant. Moreover, if a test is such as to have an effect on several crops in a rotation, the test should be carried on with all the crops involved.

An experiment should thus be carried out on several farms, over several years, and with several crops. It is obvious that to be able to determine whether the several simple effects and all the possible important interactions are significant or not, the experiment must be designed and carried out in such a way as to allow one to separate out and calculate all the important effects. An inadequate plan can only be handled with great difficulty and gives an answer that is very incomplete and that more often than not cannot be interpreted with any measurable degree of reliability.

The question may be asked as to whether replication on each farm is necessary. The answer depends upon what information is being sought. If, as has been suggested, one is seeking to obtain a basis for making recommendations in general, or even in a given district, a single test of an experiment on each of a number of farms is satisfactory, for the interaction of treatments and farms furnishes a measure of the uncontrolled variability, and so can very satisfactorily be used to test the significance of average treatment differences. The different farms in this case correspond to different replications in the district. One cannot expect to measure small differences in the effect of treatments in this way, because the interaction of farms and treatments is apt to be fairly large. On the other hand, if one is investigating a problem in which it is necessary to have information regarding the response at individual farms or places, then, replication on each farm is necessary to get a measure of the uncontrolled variability applicable to each farm. The frequency of replication depends upon the size of the difference that it is important to detect.

In many cases it is sound in principle and more economical to get as much information as can be got before attempting to generalize. For this purpose a comprehensive experiment under conditions controlled as much as possible is desirable. This may be illustrated by reference to the study of a disease problem. If it is suspected that soil deficiencies are responsible for causing disease in any crop, the problem would first be studied on a soil where the disease is apt to occur. Numerous treatments that might have some influence on the control of disease would be studied under conditions controlled as far as possible so that any real effects may be revealed. Having revealed the contributory deficiencies, it would then be opportune to try out the correctives under several other conditions and so determine if the results can be generalized.

In addition to such interactions as have been discussed, it should be said that interactions are very general and are often very important. To get information on them it is very necessary to design experiments so that they may be separated out. To illustrate the matter, reference is

made here to a problem which presented itself at Macdonald College a few years ago. As the result of long-continued application of a certain fertilizer treatment to an area of land, the growth of the mangel crop was very poor and quite abnormal. For reasons which need not be gone into here, a deficiency of calcium, phosphorus, potash and magnesium were suspected. Plots were laid out to include all possible combinations of these elements together with a nil plot. The experimental plan is shown in Figure 2. The sixteen treatments were randomized in each of two blocks.

	Nil	P	K	PK
Nil	Nil	P	K	PK
Ca	Ca	CaP	CaK	CaPK
Mg	Mg	MgP	MgK	MgPK
CaMg	CaMg	CaMgP	CaMgK	CaMgPK

FIGURE 2

The plan of this experiment allows not only for the determination of the simple effects of calcium, phosphorus, potash and magnesium, but also for all the possible interactions. For example, does phosphorus or potash applied separately give the same effect as they do when they are applied together? The following are the simple effects and interactions which may be obtained.

Simple effects	Interactions		
	First order	Second order	Third Order
Ca P K Mg	Ca × P Ca × K Ca × Mg P × K P × Mg K × Mg	Ca × P × K Ca × P × Mg Ca × K × Mg P × K × Mg	Ca × P × K × Mg

There are thus four simple effects, six first order interactions, four of second order, and one of third order. For each simple effect and interaction there is one degree of freedom making fifteen in all. The sum of squares for each may be calculated from the difference between the sum of half the plots and the sum of the other half. This is done by squaring the difference, dividing the result by two, and again by the number of plots included in each sum to reduce it to a single plot basis. The simple effect of any one fertilizer may be got from the difference between the sum of all the plots receiving that fertilizer and the sum of all the plots not receiving it. The first order interaction of one fertilizer with another may be obtained from the difference between all the plots receiving one or the other, and the sum of those receiving both or neither. The second order interaction may be computed from the difference between the sum of all plots receiving all three or only one fertilizer, and the sum of all those receiving

two or none. The third order interaction may be determined from the difference between the sum of all the plots receiving one or three fertilizers, and the sum of all those receiving two or four fertilizers or none. The diagrams appearing in Figure 3 (page 310) illustrate how the direct effects and the interactions may be obtained.

An analysis of variance of the yields of dry matter obtained in this experiment gives the results shown in Table 3.

TABLE 3.—ANALYSIS OF VARIANCE OF A FERTILIZER EXPERIMENT WITH MANGELS (ROTATION FARM 1935)

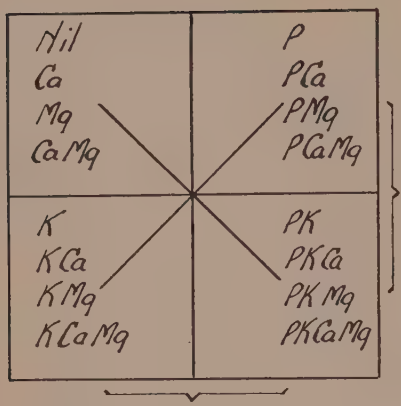
Source of Variance	Sum of Squares	D.F.	M. Sq. or Variance	$\frac{1}{2}$ $\log_e$	z Value Obtained	z Value for P = .05
Treatments	133.31	15	8.88	1.09	.57	.45
Ca	3.78	1	3.78	.66	.15	.75
P	86.21	1	86.21	2.22	1.71	.75
K	11.14	1	11.14	1.20	.69	.75
Mg	3.97	1	3.97	.69	.17	.75
Ca × P	20.89	1	20.89	1.52	1.00	.75
Ca × K	.26	1	.26	—	—	—
Ca × Mg	.00	1	.00	—	—	—
P × K	.07	1	.07	—	—	—
P × Mg	2.20	1	2.20	—	—	—
K × Mg	.04	1	.04	—	—	—
Ca × P × K	.01	1	.01	—	—	—
Ca × P × Mg	.18	1	.18	—	—	—
Ca × K × Mg	.59	1	.59	—	—	—
P × K × Mg	.61	1	.61	—	—	—
Ca × P × K × Mg	3.29	1	3.29	—	—	—
Blocks	25.03	1	25.03	1.56	1.05	.75
Error	41.99	15	2.80	.51		
Total	200.33	31				

Standard error = 1.67

This analysis of variance shows that of the simple effects of the several fertilizers; phosphorus is the only one that has given a significant difference, and its difference is away past the point of significance. Of the first order interactions, only one is significant, namely, that of Ca × P. In this case examination of the treatment means reveals that it is a depressive effect. In other words, the increment in yield from calcium and phosphorus when applied together was less than the sum of the increments obtained when these substances were applied separately. Since there is no simple effect from calcium and there is with phosphorus, one possible explanation is that the calcium is reacting in such a way that the phosphorus is not as available as when applied separately. There are no other significant differences. The differences between the treatments in general, as measured by the sums of squares, have thus been analyzed out in all possible ways to make up the total. It is obvious in this case that without a proper design of the experiment it would not have been possible to determine efficiently the effect that each fertilizer is having by itself or by its interactions with others.

It is important to note that the variances which we get are not obtained by comparing one treatment against a nil treatment, but represent rather the average effect under all the conditions imposed. For example, the

Direct Effect and First Order Interaction



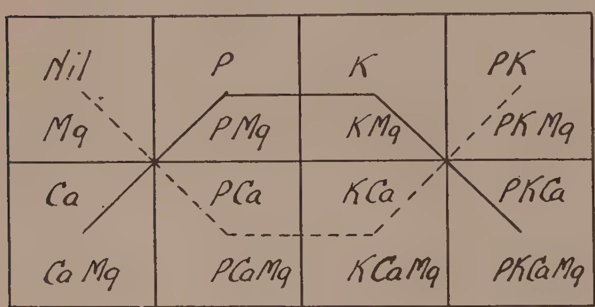
Direct effect of K from these two totals.

Interaction of P on K from the diagonal totals.

Direct effect of P from these two totals.

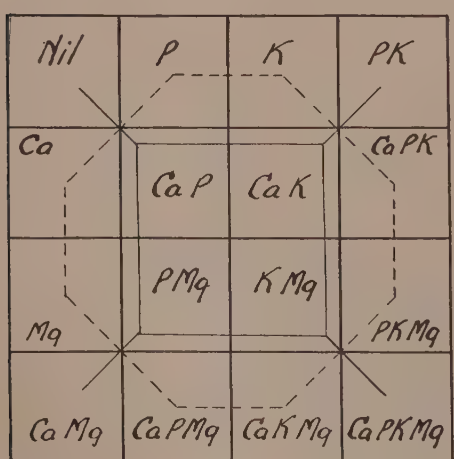
Second Order Interactions

Interaction of Ca × P × K determined from the two totals:



(1) those receiving all three or one of these treatments (*i.e.*, treatments in cells joined together by solid lines).
(2) those receiving two or none of them (*i.e.*, treatments in cells joined together by dotted lines).

Third Order Interactions



Interaction of Ca × P × K × Mg determined from the two totals:

(1) those receiving one or three of these treatments (joined together by dotted lines).

(2) those receiving four or two or none of them (joined together by solid line).

FIGURE 3

variance obtained for phosphorus is a measure of the average effect of phosphorus versus no phosphorus under the following conditions: without any other treatment, with potash, with calcium, with magnesium, and with all the several combinations of these elements. This result, when taken along with other results obtained, furnishes the most reliable information obtainable as to the effect of phosphorus.

It may occur to some that this makes a complicated experiment, takes a lot of plots, and permits only a few replications. It should be pointed out that the extra plots used in this way are not wasted but are used most efficiently as replications. In this case there are sixteen plots with phosphorus, and sixteen plots similar in every way without phosphorus. In the same way, in obtaining the variance for each of the other simple effects and interactions, all thirty-two plots have been used, *i.e.*, sixteen versus sixteen.

In all field experiments with soils, it is important to observe what Fisher has termed "Principles of Field Experimentation," namely, replication, randomization and local control.

Replication is necessary in order that we may get an estimate of the error that must be considered in interpreting results. Further, it is important because it is most effective in reducing the error, for with a given variability the standard error of a mean varies inversely as the square root of the number of plots involved.

Randomization is necessary in order that the observed error between plots treated alike may provide a valid estimate of the errors affecting treatment comparisons. If plots are not randomized, the observed error may be too large or it may be too small. If it is too large then the apparent variance arising from sources will be reduced, and no significance will be shown in some cases where it really exists. On the other hand, if it is too small then the apparent variance due to other sources will be too large, and a significant difference may be deduced where one does not actually exist. Since the significance of any difference has to be determined by its relation to its error, it is obvious that lack of randomization will often result in erroneous conclusions. This is true in theory, and has also been found to be so in practice.

By local control is meant that the experiment is so arranged that we can calculate the average effect of differences in locality and so eliminate it from the error. By this means the error may be much reduced. The principal methods of doing this are by putting each replication in a compact block, and by arrangement of the treatments in a latin square with all treatments occurring once and only once in each column and in each row. This latter allows for the elimination of average differences in the soil in two directions at right angles. In addition to these main methods a number of modifications based upon these principles are also in use.

In conclusion it should be said that the application of statistical methods may not always be necessary. This is true, for example, where differences are found to be very large, and where previous information has been obtained from which one has some measure of the differences that are required for significance. In most classes of work, however, the proper planning of experiments, and the sound application of statistical methods, will bring out much information that is not otherwise attainable, and that is necessary for proper interpretation of results obtained.

TESTING THE FERTILITY OF ALBERTA SOILS BY THE NEUBAUER AND LEMMERMANN METHODS[1]

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Numerous field experiments with the use of commercial fertilizers have been conducted throughout Alberta during the past several years. The results obtained from these experiments have led to the fairly general use of fertilizers. Field experiments are very valuable but are rather cumbersome and time-consuming for general use. It was hoped that one of the laboratory methods might be used to indicate the possible field responses from fertilizers. Several methods have been tried in recent years with the object of determining plant available phosphorus in Alberta soils (1). Total phosphorus and water soluble phosphorus as well as phosphorus soluble in a .002N H_2SO_4 solution have been determined. No close relationship, however, between the data so obtained and field results could be found.

Later two other methods for determining available phosphorus in soil were tried out as to their value for Alberta soils: viz., the Neubauer method and the Lemmermann method. As the results of these trials have been quite favorable, it is thought advisable to report on them in detail.

METHODS

The Neubauer Method for Determining Plant Available Phosphorus and Potassium in Soils

Neubauer concluded that if a great number of germinating plants grew in a small amount of soil, the roots would penetrate the soil completely and take up most of the available plant food. It would be only necessary to determine the amount of phosphorus and potassium taken up by the plants to have a fair indication of the nutrient condition of the soil. This method is based upon the fact that germinating plants have a very great absorptive power for nutrients. The procedure followed in making Neubauer determinations is given below.

One hundred rye kernels are placed in 100 grams of soil mixed and covered with 300 grams of sterile glass-sand. After 18 days growth, the plants are removed from the soil and their phosphorus and potassium content is determined. Parallel experiments are conducted in the same way with sterile sand alone. The difference between the phosphorus and potassium content of the plants grown in soil and those grown in the sand gives the amount of phosphorus and potassium taken from the soil.

The details of the seedling method are given in Neubauer's original report of 1923 (7) and more recently in the text book on plant nutrition by Honcamp (6). If the rye seedlings have removed five or more milligrams of P_2O_5 and 20 or more milligrams of K_2O from 100 grams of soil, Neubauer assumes that the soil is well supplied with these nutrients for the production of grain in an available form under average conditions of

[1] This paper was constructed from a thesis submitted to the University of Alberta in partial fulfilment of the requirement for the degree of Master of Science, April, 1932. Grateful acknowledgment is made to Dr. F. A. Wyatt and Dr. J. D. Newton for their advice, co-operation and encouragement.

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farming in Germany; for most other crops, especially legumes, these requirements are somewhat higher. Whether or not these limiting values will be applicable under the entirely different conditions of Western Canada was to be determined through the investigations reported here.

The Lemmermann Method for Determining Available Phosphorus in Soils

Lemmermann assumes that the ratio of readily soluble phosphorus, measured by its solubility in a weak solvent, to the total amount of phosphorus in the soil gives a good indication of the availability of soil phosphorus for plant nutrition. From theoretical consideration it appears that the relative solubility can not be an indication of the phosphorus supply where the total phosphorus content is very low.

The technique of the Lemmermann method consists of determining the total and the 1% citric acid soluble phosphorus, and in calculating the percentage of total phosphorus soluble in citric acid. If this is higher than 25% and the total phosphorus higher than 25 milligrams P_2O_5 per 100 grams of soil, Lemmermann assumes that the soil is well supplied with available phosphate. If the relative solubility is between 20 and 25% it is dubious whether the soil contains enough available phosphorus for the production of a good crop or not. The details of the Lemmermann method are given in the original papers (4, 5).

The Soils Used in the Investigation

As it was the purpose of this research to determine the adaptability of methods for the determination of available phosphorus and potassium in the soils of Alberta, it was necessary to use soils representing the major soil groups existing in the province. The samples used in these tests were taken from the International Boundary to the Peace River district and represent the following four soil groups; brown prairie soils, black parkland soils, gray podsol-like wooded soils, and the transition soils between the latter two. Descriptions of these soil types can be found in the publications of Wyatt, Newton, Leahey, Doughty and Holowaychuk (8, 9, 3, 1, 2).

In these first studies with the Neubauer and Lemmermann tests it was deemed advisable to use typical soil samples whose responses to phosphorus fertilization were known. Time and facilities made it possible to work with 33 such samples distributed as follows: 7 brown soils, 11 black soils, 7 black-gray transition soils, 7 gray wooded soils, and 1 peat.

Experiments with potassium fertilizers had hardly been made at all in Alberta, and therefore the results of the Neubauer tests for potassium are merely recorded and no attempt made to draw any conclusions from these data.

RESULTS

The Neubauer Tests

Table 1 shows the results of the Neubauer analyses and of the field experiments, thus giving an opportunity to draw conclusions as to the reliability of the Neubauer method under Alberta conditions. The results are summarized in Table 2 in order to enable a comparison of the number of samples that do and those that do not show correspondence between Neubauer data and field results.

TABLE 1.—FIELD RESPONSE TO PHOSPHATE FERTILIZATION AND NEUBAUER DATA

Soil group	Sample No.	Location	Texture	Crop used in experiment	Field response to P_2O_5 treatment	Does Neubauer figure for P_2O_5 confirm field result?	Neubauer figure	
							mgm. P_2O_5	mgm. K_2O
Brown prairie soils	1	Brooks	Fine sandy loam	—	No	Yes	18.0	35.5
	2	Turin	Silt loam	Wheat	Yes	No	6.4	47.1
	3	Coutts	Loam	Wheat	Yes	Yes	1.4	29.6
	4	Barnwell	Loam	Beets*	Yes	Yes	2.8	21.3
	5	Taber	Sandy loam clay	Beets*	Yes	Yes	2.5	24.2
	6	Lethbridge	Clay loam	Beets*	Yes	Yes	4.7	36.6
	7	Lethbridge	Silt loam	Wheat	Yes	Yes	4.6	30.5
Black parkland soils	8	Clyde	Clay loam	Wheat	Yes	No	12.6	31.1
	9	Leduc	Silt loam	Wheat	Yes	Yes	3.9	18.8
	10	Clyde	Silt loam	Potatoes	No	Yes	15.8	54.2
	11	Spruce Grove	Clay loam	Wheat	Yes	Yes	2.4	14.3
	12	Edmonton	Loam	Grass and clover	No	Yes	14.2	29.5
	13	Edmonton	Loam	Grass and clover	No	Yes	10.0	30.1
	14	Edmonton	Loam	Grass and clover	No	No	1.8	15.4
	15	Edmonton	Loam	Grass and clover	No	Yes	5.0	18.4
	16	Edmonton	Clay loam	Wheat	Yes	Yes	3.3	36.3
	17	Edmonton	Clay loam	Wheat	Yes	Yes	3.7	30.9
	18	Edmonton	Clay loam	Oats	Yes	Yes	3.9	34.9
Black-gray transition soils	19	Fairview	Clay loam	Wheat	No	Yes	7.3	40.4
	20	Fairview	Clay	Wheat	No	Yes	14.5	43.4
	21	Duffield	Loam	Alfalfa	Yes	No	10.1	21.8
	22	Onoway	Loam	Barley	No	Yes	7.2	19.0
	23	Duffield	Loam	Alfalfa	No	Yes	20.9	30.5
	24	Tofield	Loam	Alfalfa	Yes	No	14.7	29.0
	25	Tofield	Loam	Sweet clover	No	Yes	11.9	25.4
Gray podsol like wooded soils	26	Warburg	Loam	Wheat	Yes	No	7.7	25.8
	27	Breton	Silt loam	Wheat and oats	Yes	Yes	3.8	10.9
	28	Fallis	Loam	Wheat	Yes	Yes	4.0	16.1
	29	Breton	Loam	Alfalfa	Yes	Yes	6.8	17.0
				Grain	Slight			
	30	Breton	Loam	Wheat	Slight	No	3.3	17.2
	31	Breton	Loam	Sweet clover	Yes	Yes	6.4	17.7
	32	Fallis	Loam	Clover mixture	Yes	Yes	4.3	8.8
Peat soil	33	Darwell	—	Potatoes	Yes	Yes	7.0	21.7

*Irrigated.

The Lemmermann Tests

Nine of the samples used for the Neubauer analyses were used for testing the adaptability of the Lemmermann method for Alberta conditions. Table 3 shows the results thus obtained. The numbers of the soil samples refer to those given in Table 1.

TABLE 2.—SUMMARY OF RELATIONSHIP BETWEEN NEUBAUER DATA AND FIELD RESULTS FOR 33 ALBERTA SOILS

Soil group	Number of samples	Number and percentage of samples showing correspondence between Neubauer figure for P_2O_5 and field results	
		No.	%
Brown prairie soils	7	6	86
Black parkland soils	11	9	82
Transition soils	7	5	71
Gray wooded soils	7	5	71
Peat soil	1	1	100
Total	33	26	79

TABLE 3.—FIELD RESPONSE TO PHOSPHATE FERTILIZERS AND LEMMERMANN DATA

Soil group	Brown prairie soils		Black parkland soils				Black-gray transition soil	Gray wooded soils	
Soil Sample No.	1	3	9	10	11	17	23	30	32
Total P_2O_5 Aqua Regia extraction. Mgms. of P_2O_5 in 100 gms. of air dry soil	161.0	152.5	187.8	283.1	198.4	226.8	222.6	163.6	194.0
Citric acid extraction. Mgms. of P_2O_5 in 100 gms. of air dry soil	55.1	23.2	7.5	100.1	11.2	13.5	61.3	38.1	38.1
Relative solubility	34.2%	15.2%	4.0%	37.0%	5.7%	3.8%	27.5%	23.4%	19.7%
Does Lemmermann result indicate response to P_2O_5 fertilizers?	No	Yes	Yes	No	Yes	Yes	No	Dubious	Yes
Field response to P_2O_5 treatment	No	Yes	Yes	No	Yes	Yes	No	*	Yes

*Yes for legumes, no for grains.

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DISCUSSION

From the results obtained in this investigation it appears that both the Neubauer and the Lemmermann methods are applicable under Alberta conditions. The limited number of trials suggest the need for further investigation in this line. It will be important to find out which one of the two methods is the more useful. The drawback of the Neubauer method is the comparatively large amount of work and the necessity of having a room of fairly constant temperature (18°–22° C.) for the growing of the rye seedlings. The Lemmermann method can be carried out in any well equipped chemical laboratory. One of the main difficulties of this method is the neutralization of the citric acid by carbonates. A perfect compensation by adding correspondingly more citric acid is practially impossible.

As the Neubauer method used plants for the determination of available plant nutrients it might be expected to be reliable and is actually frequently used as a standard method. Lack of success with it may be often attributed to deviations from the original Neubauer procedure. The results seem to indicate that the critical figures suggested by Neubauer and Lemmermann for German conditions are also applicable for Alberta conditions.

SUMMARY

The purpose of the work reported in this paper was to find out if the Neubauer and Lemmermann methods for the determination of available phosphorus were adapted to Alberta conditions.

Studies reported in this paper consisted of the determination of available phosphorus and potassium by the Neubauer method and of available phosphorus by the Lemmermann method.

For this purpose various soils were collected from different soil groups in Alberta. These samples were taken from fields whose response to phosphorus fertilizers was known. Thirty-three samples were subjected to the Neubauer test, and nine samples were subjected to the Lemmermann test.

Seventy-nine per cent of the soils used showed correspondence between laboratory analyses and field results in the case of the Neubauer method, and in the case of the Lemmermann method all nine samples analysed showed correspondence with field results.

The critical figures used by Neubauer and Lemmermann for indicating the boundary between soils needing and soils not needing phosphorus fertilizers seem to apply for Alberta soils.

The results of the determinations of available phosphorus in Alberta soils by the Neubauer, as well as by the Lemmermann, method have been very promising. However, the limited number of samples used suggests the need for further work before either of these methods might safely be advocated for general use.

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Résumé

Détermination de la fertilité des sols de l'Alberta par les méthodes Neubauer et Lemmermann, Helmut Kohnke, Université de l'Alberta, Edmonton, Alberta.

Cet article traite des recherches qui ont été faites pour connaître l'utilité de la méthode Neubauer pour la détermination du phosphore et de la potasse "assimilables" et celle de Lemmermann pour la détermination du phosphore assimilable dans les sols de l'Alberta (Canada).

Les résultats de ces recherches ont été très favorables si elles indiquent que les chiffres critiques proposés par Neubauer et Lemmermann pour les conditions allemandes s'appliquent également aux conditions de l'Alberta.

A STUDY OF THE NITROGENOUS FRACTION OF SOILS[1]

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INTRODUCTION

Two processes take place in soil genetics: the process of formation of organic matter resulting from the decomposition of plant and animal remains with a subsequent accumulation of these decomposition products; and the process of destruction of soil organic matter. A change in the organic matter in the soil, depending on which of these processes is predominant, may be observed.

During the first stages of soil-formation, the process of formation of organic matter is predominant, the destruction of organic matter is small, and hence its amount in the soil increases.

Conditions may occur during the subsequent stages of soil formation that are more favourable to the process of destruction of organic matter in the soils. Consequently a gradual decline of soil humus will take place.

The plant species and their composition vary widely both qualitatively and quantitatively on different soils. Their decomposition is brought about by the action of various micro-organisms under different climatic conditions, and consequently qualitative differences in their decomposition products might be assumed *a priori*.

We can speak with a certain degree of approximation of the composition of soil humus, but, so far, it has been found impossible to establish the qualitative differences which exist in the organic matter of different soils. Until more is known of the molecular constituents of the soil organic matter, the observed inconsistencies in plant-response toward organic matter will remain unanswered.

REVIEW OF THE LITERATURE

It is believed by many workers that soil organic nitrogen exists largely or totally in the form of proteins. Schmuck (4) believes that 60–80% of the total nitrogen in the soil belongs to the protein fraction. Remesow and Werigina (3) report that all the nitrogen which is hydrolyzed by hydrochloric acid is of protein nature.

The fact that not all of the nitrogen in soils is hydrolyzed by mineral acids has often been brought forward as an argument that a considerable fraction of this nitrogen is of non-protein nature, but is present in the form of ring nitrogen compounds.

Waksman and Iyer (6) prepared artificial humus from casein and lignin, and compared the extent of hydrolysis of these preparations with that of natural humus.

	Unhydrolyzed fraction
Casein	6.8%
Lignin	94.3
H-ligno-proteinate	89.3
Ca-ligno-proteinate	80.3
Humus from peat	83.0

[1] Read before a joint session of the Soils Group of the C.S.T.A. and the Canadian Phytopathological Society at the University of New Brunswick, Fredericton, N.B., July 14–15, 1936.

It may be seen from this table that natural humus is intermediate between H-ligno-proteinate and Ca-ligno-proteinate, and hence behaves in the same manner as the artificial "humus" preparations. Again, the behaviour of artificial humus preparations toward acetyl bromide, according to Waksman and Iyer is analogous to that of natural humus. They found that whereas proteins are completely, and lignin almost completely, dissolved by acetyl bromide, the artificial humus preparations, like natural humus, were attacked only to a limited extent. Waksman's conclusion is that the non-hydrolyzed nitrogen fraction belongs to the proteins bound in some stable lignin complex.

Shorey (5), working on Hawaiian soils, states that approximately 50% of the nitrogen extracted by a 12% boiling HCl solution is in a form unlike the products of decomposition of protein bodies. Shorey treated the HCl solution of the soils according to the method of Osborne and Harris (2) and compared his results with those of these workers who worked on pure protein bodies. Shorey's results are as follows:

Fractions of nitrogen in the HCl extract.

Ammonia nitrogen	11.9%
Nitrogen precipitated by magnesia	28.0
Basic nitrogen	14.0
Non-basic nitrogen	8.4
Total nitrogen in solution	62.3

The most striking point is the large amount of nitrogen in the magnesia precipitate. It amounts to 54.2% of the total nitrogen in the hydrochloric acid extract, whereas, in the case of pure proteins, this fraction does not exceed and in most cases is considerably less than 4% of the nitrogen in the hydrochloric acid solution.

Shorey (5) also approached the nitrogen problem from a different angle. A number of Hawaiian soils were subjected to dry distillation. The alkalinity of the distillates was found to be equivalent to 16.8%, and the nitrogen fraction, as determined by the Kjeldahl method, amounted to 14.5% of the total nitrogen of the soil. Although Shorey does not offer any explanation for the difference between the titration results and those obtained from the Kjeldahl analysis, it would appear that pyridine and quinoline bases might be responsible for the discrepancy. The odour of pyridine was detected by Shorey in the distillates thus obtained. From a sodium hydroxide extract of Hawaiian soils, Shorey has obtained and identified the silver salt of picoline carboxylic acid.

RESULTS AND DISCUSSION

It was thought that if pyridine and quinoline derivatives were present in the soil in any appreciable amounts, the Dumas method for the determination of nitrogen should give higher results than the Kjeldahl method, as the pyridine and quinoline nitrogen is not determinable by the Kjeldahl method.

A number of organic soil samples were analyzed for nitrogen by both the Kjeldahl and the Dumas methods with the results shown in Table 1.

TABLE 1

	Per cent N_2 Kjeldahl	Per cent N_2 Dumas
Surface-soil muck		
1	1.28	1.56
2	1.42	1.98
3	1.54	1.91
4	2.47	3.28
5	1.88	2.01
6	2.21	2.70
Sub-soil muck		
1	2.40	3.41
2	1.86	2.16
3	1.89	2.50
4	2.20	3.12
5	2.62	3.63
6	2.15	2.76
Raw humus		
1	1.47	1.92
2	1.52	1.86
3	1.43	1.68

The results in Table 1 show that there are considerable differences in the percentages of nitrogen in organic soils as determined by the Kjeldahl and the Dumas methods. In the soils examined 6.4 to 29.6% of the total nitrogen is non-determinable by the Kjeldahl method. It would appear, therefore, that an appreciable fraction of soil organic nitrogen is in the form of ring nitrogen or in the form of some stable compounds in which nitrogen is linked to nitrogen.

The question might occur as to whether Waksman's "ligno-protein complex," which is stable toward hydrolysis with mineral acids, may not be responsible for this difference. However, upon inspection of Table 2 it may be seen that there is a difference between the nitrogen contents of the hydrolysates as well as between those of the non-hydrolyzed fractions. Furthermore, there are two cases, the raw humus samples, 1 and 3, where the nitrogen content of the non-hydrolyzed fraction, determined by the Kjeldahl method, is equal to that of the Dumas method. This appears to exclude the likelihood that Waksman's "ligno-protein complex" is the cause of the difference in nitrogen content shown by the two methods.

The isolation of soil organic nitrogen compounds was attempted using various organic solvents, such as methyl, ethyl, butyl alcohol, acetic acid,

TABLE 2

Soil	N_2 expressed as percentage of total Dumas nitrogen of the soil			
	Per cent nitrogen of hydrolysate		Per cent N_2 of residue	
	Kjeldahl	Dumas	Kjeldahl	Dumas
Surface muck				
1	52.37	64.59	26.44	36.73
2	50.28	68.40	22.05	31.28
3	58.29	73.21	24.53	27.76
Sub-soil muck				
1	58.17	64.19	28.82	36.36
2	57.80	69.39	21.49	30.64
3	50.31	63.40	29.60	36.19
Raw humus				
1	58.35	80.20	18.46	18.99
2	64.40	74.49	14.36	25.16
3	65.35	80.12	19.37	19.49

chloroform, carbon disulphide, ethylene glycol, glycerol, and others. However, this procedure proved to be unsatisfactory. With the exception of glycol and glycerol, all these solvents extract but a small fraction of the nitrogen compounds, and the high boiling point and the high viscosity of glycerol make the mark with this solvent cumbersome.

An attempt was made to isolate nitrogen compounds from the soil by distilling the soil with sodium hydroxide *in vacuo*. The distillate is quite basic containing ammonia, amines, and pyrrole and pyridine derivatives. Pyridine ferrocyanide and quinoline dichromate were obtained from the distillate when the acidified concentrated solutions were treated with potassium ferrocyanide and potassium dichromate. It was also found that the nitrogen content of the distillate when calculated from titration data compares very favourably with the nitrogen values obtained by the Dumas method.

It was thought that the amido and the mono-amino nitrogen fractions of the hydrolysates might, within a narrow range, show more or less constant values for the same soil-type. Table 3 shows that, although definite ranges exist among the soil types, these are by no means narrow.

The raw humus soils and the raw moss peats show similar properties in so far as their mono-amino nitrogen contents fall within the same range. Furthermore, the amido nitrogen fractions of the raw humus soils lie within the same range as do those of the Ontario peats, but they do not correspond at all with those of the Quebec peats. This difference is of interest and is probably due, in part, to the difference in the states of decomposition of these peats.

Particularly striking are the results obtained from the hydrolysis of muck surface-soils and muck sub-soils. It should be noted that the former are considerably higher in both the amido and the mono-amino nitrogen fractions, which, it would seem, are the least stable fractions of soil organic nitrogen.

TABLE 3.—SHOWING AMIDO AND MONO-AMINO NITROGEN FRACTIONS IN THE HYDROLYSATES

—	Per cent amido nitrogen	Per cent mono-amino nitrogen
Muck surface-soils		
1	16.94	59.23
2	17.55	60.57
3	10.00	57.29
Muck sub-soils		
1	10.42	32.21
2	8.40	48.69
3	6.84	46.61
4	5.30	48.43
Raw humus		
1	5.19	73.86
2	9.54	73.36
3	8.62	66.18
Raw moss peats		
Quebec Peats 1	18.71	69.00
Quebec Peats 2	22.52	77.25
Ontario Peats 3	6.65	76.30
Ontario Peats 4	8.75	68.52
Ontario Peats 5	6.30	73.49
Brown earths		
1	7.42	79.25
2	10.94	90.10
3	11.00	89.49
Black earths		
1	11.97	87.40
2	10.83	66.73
3	13.40	64.81

According to Dragunow (1) the amido and the mono-amino nitrogen fractions of Russian peats constitute the total nitrogen content of their hydrolysates. In view of this, the results in the above table are unexpected since only one of the peats investigated, raw moss peat 2, shows a similar behaviour.

Among the samples studied there are found three other cases analogous to that of peat 2. These are the brown earths, 2 and 3, and one of the black earths 1. This shows that the absence of Remesow's (3) "di-amino nitrogen" fraction is not confined to peats alone, but is evident in other soils as well.

The results in Table 3 are not extensive enough to permit a far-reaching generalization. One point, however, is made clear, namely, that qualitative differences occur in the nitrogen compounds of different types of soils and, to a less extent, in the nitrogen compounds of soils of the same type.

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Résumé

Etudes des fractions azotées des sols. A. W. J. Dyck et R. R. McKibbin, Collège Macdonald, P.Q.

L'analyse d'une série de sols organiques a démontré que la méthode Dumas donne un chiffre d'azote plus élevé que la méthode Kjeldahl. C'est, croit-on, parce qu'une fraction appréciable de l'azote organique du sol existe sous forme de dérivés de pyridine et de quinoline. Les pyridine, pyrole et quinoline ont été isolées des distillés obtenus lorsque les sols mélangés avec de l'hydroxide de sodium ont été distillés à vide. Un tableau donne les fractions d'azote amido et mono-amido dans les différents sols.

THE USE OF HYDROFLUORIC ACID IN SOIL ANALYSIS

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The fusion method of soil analysis with sodium carbonate has certain objectionable features, and it was with the idea of overcoming these that treatment of soils with hydrofluoric and sulphuric acids was undertaken.

The method used is as follows: 1 gram of clays or 2 grams of sands, ground to pass 100 mesh, are gently ignited in a platinum dish until the organic matter is destroyed. The soil is then thoroughly wetted with 5 cc. of water, then 10 cc. of hydrofluoric acid and .5 cc. of sulphuric acid are added. The dish should preferably have a flat bottom. The mixture is then slowly evaporated on a hot plate until (H_2SO_4) fumes are evolved. After cooling, 5 cc. of water is added to dissolve the salts and then 5 cc. of hydrofluoric acid and second evaporation takes place. The residue is dissolved in water and a few drops of HCl, filtered and washed. If an insoluble residue is evident, it may be ignited with the paper and a further treatment with HF and H_2SO_4 made. This is rarely necessary.

In some soils a residue of .2% was left. Spectrographic examination showed it to consist largely of titanium, boron, and silicon, possibly a titanium boro-silicate.

The use of HF eliminates practically all the silica and so does away with the tedious dehydration and numerous washings of this substance. Further, the NaCl necessarily formed in dissolving the Na_2CO_3 fusion is not present and two precipitations of the bases as against three with Na_2CO_3 fusion are sufficient.

If the amount of silica is required, it can be separately determined on a small quantity of soil by fusion with sodium carbonate.

The objections to the method are few. The most obvious is the HF itself, which must be evaporated in a fume-chamber with a good draft.

One precaution is to be noted, that a little of the precipitate of alumina and ferric hydroxide may pass through the filter paper unless it is washed with slightly ammoniacal 1% ammonium nitrate solution.

The HF method has also been used in the estimation of potash, in place of the Lawrence Smith method of treating with ammonium chloride and calcium carbonate. It has proved quite satisfactory if the alumina and ferric hydroxide are precipitated twice, and is perhaps somewhat faster.

The saving in time by the HF method compared with the fusion method in our experience has been two days for each batch of samples.

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[1] Assistant Chemist.

The accompanying table gives the results obtained by this method and the fusion method and shows that the variation in results is not great, those for alumina being the widest.

Na_2CO_3 FUSION VS. HF AND H_2SO_4

Sandy loams	1		2		3		4	
	Fusion	HF	Fusion	HF	Fusion	HF	Fusion	HF
CaO	.64	.61	1.31	1.33	.66	.53	.53	.53
MgO	.88	.97	.98	.96	1.76	1.85	1.85	1.78
Fe_2O_3	6.00	5.94	5.57	5.45	7.23	7.11	5.20	5.25
Al_2O_3	11.17	11.01	10.85	10.90	14.18	14.87	12.35	12.43
Clay loams	1		2		3			
CaO	2.54	2.41	2.67	2.54	2.98	2.79		
MgO	2.72	2.70	3.64	3.72	3.90	3.83		
Fe_2O_3	7.90	7.26	9.44	9.24	9.25	9.03		
Al_2O_3	17.61	16.74	18.66	18.15	18.63	18.00		

Résumé

L'emploi de l'acide hydrofluorique dans l'analyse du sol. H. S. Hammond, Ferme expérimentale centrale d'Ottawa.

Deux méthodes d'analyse ont été comparées pour l'évaluation de la teneur en chaux, en magnésium, en oxyde de fer et d'alumine, savoir, le traitement par les acides hydrofluorique et sulfurique en fusion avec le carbonate de sodium. Les deux méthodes ont donné des résultats très semblables, mais la première a exigé beaucoup moins de temps que la dernière.

THE CLAY FRACTION OF ANNAPOLIS VALLEY SOILS[1]

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In the Maritime provinces only a start has been made on definite soil survey work; nevertheless much consideration has been given to the proper utilization of land for crops such as fruit, hay, forest, etc. As crops fail we are forced to estimate the relative value of factors which lead to such a result; high cost of production emphasizes the need of detailed knowledge of our soil. The first detailed soil survey of any part of Nova Scotia was begun in 1934 to cover that part known as the Annapolis Valley. The primary purpose of this survey was to correlate soil conditions with the incidence of certain disorders of fruit.

Geographically this area includes that spoken of by Longfellow in his poem Evangeline as—"This is the forest primeval. The murmuring pines and the hemlocks, bearded with moss," etc. It is adjacent to the Bay of Fundy in latitude 44° 45′ to 45° 10′. The temperature rarely goes over 95° F. or drops to −10°; the average for the last 16 years has been 42.7°.

The soil map of Canada places the Annapolis Valley in the A_3, or the central area of the Acadian Forest climax which has Thornthwaite values of precipitation effectivity index 132.6, the highest in Canada, and temperature effectivity index of 38.1.

Topographically the area is a valley from six to ten miles wide between the North and South Mountains, which are hills rising quite abruptly to the height of 500 to 700 feet above the sea level. The North Mountain protects the valley from the bleak winds and fog of the Bay of Fundy. The humidity at times is very high.

Geologically the area is interesting; eight formations are represented either on the floor or walls of the valley; weathering, *in situ*, of the characteristic rocks of these formations whether it be the Precambrian slate, the sandstone or granite of the Devonian period, the Keuper-Triassic sandstone or the doleritic lava of the North Mountain poured out on the sandstone in Triassic times, would naturally produce soils of vastly different composition. In Quaternary times glaciers covered the whole area with drift which has been the basis of the parent material of the valley proper. The bed rock of the valley is red sandstone, four hard ridges of which, running parallel to the mountains, have given rise to four parallel small rivers, the Annapolis, Cornwallis, Pereau and Habitant.

Boulder clay with large amounts of North Mountain amygdaloidal trap mantles the hills and valley. There has been a succession of submergences and elevations, so that the tidal currents running through the valley have worn out the red stone to such an extent that the contact of the trap rock of the North Mountain with the sandstone is 200 feet above the valley floor. These currents have broken up the glacial material to form beds of stratified sands with crossbedding and long bars of shifting sands varying from fine to coarse. At times on account of land depression

[1] Read before a joint session of the Soils Group of the C.S.T.A. and the Canadian Phytopathological Society at the University of New Brunswick, Fredericton, N.B., July 14–16, 1936.
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the sea has come up the rivers and formed the marine marshes as we have them to-day.

When a detailed survey was begun in July 1934, the plan was to study three disconnected 10-mile length cross-sections of the valley, one at the west end, one at the east, and one in the middle, alternating with 15-mile unsurveyed sections. As the work progressed the whole length was included with emphasis on the bottom of the valley and as much of the mountain sides as is devoted to orcharding. The survey should establish any marked differences as to the soil conditions of the North Mountain, Valley and South Mountain areas.

Field work has been completed on five cross sections, the sixth and last is now being surveyed. Up to November 1935, one hundred and eleven profiles, of from three to seven horizons have been studied in the field and mechanically analysed by the Bouyoucos method. The laboratory work is not only to check the accuracy of the field classification and to establish types as a basis for the soil map, but to provide as much information as possible as to the fertility of each type. Determinations of total nitrogen, except of most of the lower layers, available phosphoric acid, pH, and loss on ignition have been made on all samples.

The two major studies are first of the clay fraction, second of the base exchange nature of the soils.

Method one: For mechanical analysis, Bouyoucos, Soil Science Vol. 38 has been used. This gives sand, silt, coarse clay and colloid particles; coarse clay particles are five to two microns in diameter; fine clay two to one microns; and colloid less than one micron.

Method two: For the clay fraction, the material remaining in suspension in the Bouyoucos cylinder at the end of one hour was siphoned off, evaporated to dryness, and one gram ignited at about 700°. The residue was fused with Na_2CO_3 in a nickel crucible, treated for some time with HCl, and SiO_2, Fe_2O_3, and Al_2O_3 determined as in A.O.A.C. methods, from which data molecular ratios $\frac{SiO_2}{Fe_2O_3}$, $\frac{SiO_2}{Al_2O_3}$, $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ were calculated.

The clay fraction including as it does the inorganic and organic colloids of the soil is recognized to be of the utmost importance in soil fertility; recent investigations of this complex part of the soil have given somewhat more definite information as to the composition and action of the soil colloids.

The common colloidal minerals are composed of silicon, iron and aluminum; some difference of opinion exists as to the compounds; for example, Wadsworth in Soil Science, Mich. 1935, says, "there seems to be no reason for belief that SiO_2, Al_2O_3, Fe_2O_3 exist in soil colloids in any other form than the simple oxides or hydrated oxides.

Truog and Drosdoff, Soil Congress report 1935, say "The conception that this complex consists simply of a physical mixture of silica and the oxides of iron and aluminum and possibly others, held together in varying proportions by electrical charges, and exhibiting absorptive powers simply because of surface forces, has never made a very satisfying appeal. Lack of suitable methods for separating and identifying the compounds that make up the complex has prevented a solution of the problem. For the past several years the writers have been engaged in developing methods for this purpose. Although the exact nature of the substances giving rise

to the base exchange properties of soil colloids is still unsettled, our investigations lead to the belief that the empirical formula is $R_2O_3, 4SiO_2, \times H_2O$. The R_2O_3 may be either all Al_2O_3 or Fe_2O_3. Mixtures of the two may exist in the same molecule and crystal."

Drosdoff, Soil Science June 1935 suggests magnesium silicate, iron silicate and such minerals as talc with a ratio $\frac{SiO_2}{R_2O_3} = 4$.

Possibly some of this group are not impressed with the fact that soil develops "for better or for worse"—for worse as a rule under the hand of man. The parent material of a soil gradually weathers producing more or less colloidal material which moves up and down in the soil or completely out of it, in which case a soil is dead and infertile.

Three profiles are presented to illustrate the general character of the valley soils; since our problem was concerned with orchard conditions, most of the profiles are from cultivated land.

Humidity and temperature point to the existence of podsols which may be interfered with by erosion and by cultivation.

TABLE 1.—4501—ANALYSIS OF PODSOL OVER BOULDER CLAY ON PRECAMBRIAN SLATE. SOUTH WILLIAMSTON, SOD STRIP, ORCHARD, GENTLE SLOPE

Layer	1 A1	2 A2	3 B	4 C
Depth—inches	6–8	2–4	4–6	—
pH	5.5	5.4	5.1	6
Loss on ignition	5.7	2.7	—	—
Exchange capacity	12.1	7.3	11.7	12.5
Exchangeable Ca	6.8	2.5	4.7	11.7
Exchangeable Mg	0.76	0.52	1.06	1.4
Exchangeable H	4.3	3.5	4.6	2.1
Exchangeable K	0.49	0.37	0.28	0.44
Clay, %	16.0	10.0	18.0	46.0
Clay fraction				
S_1O_2/R_2O_3	3.8	3.1	2.8	2.6
S_1O_2/Fe_2O_3	22.6	14.2	13.1	12.3
S_1O_2/Al_2O_3	4.1	4.1	3.7	3.2

A1—Dark grey loam.
A2—Light grayish yellow sandy loam, some gravel.
B —Light yellow-brown to brown clay; fair structure.
C —Light brown silty clay.

Table 1—4501.

Note decrease in pH until parent material is reached; lack of gray layer as shown by a decrease of $\frac{SiO_2}{R_2O_3}$ ratio due to increase of Al_2O_3; effect of cultivation and erosion; high exchange capacity.

Table 2—4506.

Much the same condition exists as in the last profile, except lower exchangeable bases and more exchangeable hydrogen.

Table 3—4528.

Illustrates the effect of conditions which favour podsolization:—

(1) High organic matter in A
(2) Very high sand in parent material
(3) Low pH.

These result in A_2, a strongly leached layer. The clay and humic matter are saturated with hydrogen; the SiO_2 ratios are very high not only

on account of leaching out of R_2O_3 oxides, but also on account of the high proportion of humus in A, reducing the proportion of SiO_2.

The extremely low exchangeable bases are characteristic of a podsol. The Ca is fairly high in A, since grass and deciduous growths carry lime to the surface.

This profile illustrates a process, the operation of which in Scandinavia gives a soil all sand and humus, the bases, not only calcium, potash, etc., but also the iron and aluminum having been leached out. It is this leaching process which slowly destroys a soil.

The leaching of hydrated iron in colloidal form from soil to produce bog iron ore and alumina found in river water show where the bases may be carried; but as a rule the bases reach the B layer, are coagulated on account of a change in pH, and form hard pan.

TABLE 2.—4506—MIDDLETON LOAM. ORCHARD IN SOD; SLIGHTLY PODSOLIZED, SURFACE ROLLING; SOME GLACIAL DRIFT ON WEATHERED RED SHALY SANDSTONE. AREA PRODUCTIVE

Layer	1 A1	2 A2	3 B	4 C
Depth—inches	6	4–6	22.0	—
pH	4.95	4.8	6.0	6.3
Loss on ignition	6.2	5.5	—	—
Exchange capacity	11.4	9.6	14.4	13.0
Total base exchange	6.8	3.9	—	—
Exchangeable H	5.4	6.1	2	1.5
Clay, %	20.0	18.0	34.0	33.0
Clay fraction				
S_1O_2/R_2O_3	3.8	2.7	2.8	2.9
S_1O_2/Fe_2O_3	19.3	15.2	14.7	12.3
S_1O_2/Al_2O_3	4.7	3.3	3.5	3.7
Loss on ignition in clay fraction	16.4	16.4	8.7	8.0

A1—Brown loam.
A2—Grayish yellow brown sandy loam to loam.
B1—Chocolate brown clay.
C —Red brown clay with rock fragments.

TABLE 3.—4528—NICTAUX SAND PODSOL DEVELOPED FROM DECOMPOSED GLACIAL DRIFT. VIRGIN PROFILE; GENTLY ROLLING. DRAINAGE IMPERFECT

Layer	1 A1	2 A2	3 A3	4 B	5 B2	6 C
Depth—inches	2.0	6.0	15–18	6–10	6–8	—
pH	4.6	4.4	4.8	5.2	5.1	5.1
Loss on ignition	13.4	0.2	—	—	—	—
Exchange capacity	14.1	2.0	2.4	3.6	2.7	2.3
Exchangeable Ca	2.2	0.7	0.7	0.9	0.6	0.8
Exchangeable Mg	0.44	0.0	0.42	0.38	0.22	0.16
Exchangeable H	8.9	0.8	2.3	2.2	1.4	1.2
Exchangeable K	0.08	0.02	—	0.09	0.05	0.04
Total base exchange	2.4	0.5	0.6	0.5	0.4	0.6
Clay, %	3.0	4.0	6.0	6.0	5.0	2.0
Clay fraction						
S_1O_2/R_2O_3	3.7	5.9	3.8	2.1	1.8	2.0
S_1O_2/Fe_2O_3	16.2	7.2	18.2	10.7	9.4	9.8
S_1O_2/Al_2O_3	4.8	6.5	4.7	2.5	2.3	2.8
Loss on ignition	48.9	7.3	24.8	19.1	20.3	19.8

A1—Dark gray to black humus layer.
A2—Ashy gray, leached sand.
A3—Grayish yellow to yellow sand.
B1—Rusty brown compact sandy loam; hard pan.
B2—Brown to yellow brown gravelly sand.
C —Grayish yellow, stratified sand and gravel, grading into greenish yellow medium coarse sand.

ADAPTATION OF APPLE ORCHARDS IN QUEBEC TO SPECIAL SOIL TYPES[1]

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In the summer of 1935 the Quebec soil survey parties commenced field studies of the orchard soils in Quebec. In this paper the soil types planted to orchards and the suitability of different soils to this particular crop will be discussed.

It may be stated that there is no one particular soil that might be termed "orchard soil"; however, several of the soils encountered in this study are more suited for orchards than others.

Although the climate in most of the districts dealt with in this paper varies but little, great differences in soil types were found due to dissimilar mineralogical parent materials of the soils and due to variations in topography and drainage. The latter factor of course affects and modifies the soil moisture, temperature, and oxygen supply greatly.

Most of the soils studied in this work are located in the grey brown forest soil and podsol zones, according to the Russian classification. Due to the nature of the mineral parent material of the soil, which in most cases resists podsolization greatly, the larger part of these soils belongs to the grey brown forest soil group rather than to the podsols.

According to the nature and the process of deposition of the parent material of these soils, they may be divided into:—

1. Glacier deposited;
2. Sedimentary (river and marine) soils.

The first group is probably of greater importance as far as Quebec apple orchards are concerned.

According to the nature of the mineral parent materials, which has dominated the formation and development of the soils under comparatively equal climatic conditions, they fall into three classes:—

1. The sandstone moraine soils;
2. The Monteregian hill soils;
3. The soils of the Appalachian foothills in southern Quebec.

The sandstone moraine soils are mainly derived from potsdam sandstone and calciferous formations. These soils are very rich in lime and this dominates their formation and development. They occur in the southwestern part of the province and are encountered in the orchards of the Hemmingford, Chateauguay, St. Joseph du Lac, Oka, and Montreal Island districts.

The Monteregian soils are found around the Monteregian hills. They form in general a band around the base of each of these hills. Their mineral parent material consists of basic igneous rocks, mainly nepheline syenite and essexite. The soils derived from these rocks are generally somewhat acid.

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[1] Read before a meeting of the Soils Group of the S.C.T.A. at the University of New Brunswick, Fredericton, N.B., July 14–15, 1936.

[2] Soil Chemist.

The orchard soils of the Appalachian foothills are formed from more acid shists and shales.

The soils of these three distinct classes differ considerably from each other and each has some specific characteristics which have an important bearing on the development and fruiting of apple trees. Each of these three classes of soils can be subdivided into the following three sub-classes according to topographical features and drainage.

1. Normal soils which are well drained and open in their subsoils with the organic matter occurring to considerable depth.

2. Ill-drained soils in which the subsoil becomes compacted and iron-stained, and restricts somewhat the free movement of water.

3. Soils in which the subsoil is compacted to such a degree that the vertical movement of water is almost entirely stopped and a "hardpan" is formed or in the process of formation.

The first group, the well drained normal soils, in all areas are best suited for apple orchards. Subdivisions according to texture can be made in each group. Thus the normal sandstone moraine soils were divided into sandy loams, gravelly loams, and gravelly loam-shell phase. In the latter, marine shells were found in abundance.

In the normal sandstone moraine soils the water penetrates quite freely and the excess of free lime, which is obtained from the easily soluble cementing material of the sandstone, is washed out.

In the ill-drained soils the subsoil becomes compact and this restricts the free movement of water. As a result lime accumulates in the subsoil. In extreme cases with the continuous fall and rise of the water table the subsoil is compacted to such an extent that a "hardpan" is formed, in which case the lime serves as the cementing material. Under such conditions the water cannot freely penetrate downward during the wet seasons and cannot move upward during the summer dry season. In this type of soil it is not only a question of excessive or deficient moisture; the compacted subsoil will also hinder the free penetration of tree roots to some extent. Most important of all, perhaps, is the great excess of soluble lime in the subsoil. The nutrient balance of the soil solution is upset. Such apple disorders as corky core have been found on this type of soil. It has been recently shown that boron deficiency is very likely one of the causes of corky core. The excess of lime in the soil renders the boron unavailable to the tree. This excess of lime must be taken into consideration in the recommendation of the proper fertilizer treatments. In general, then, it may be stated that this ill-drained, high lime soil is not particularly well suited for orchards.

An excess of lime is also found in the "shell phase" of the normal soil. In this case the high lime content is not due to a concentration but rather to the presence of shells that have been transported and deposited in the glacial shifting of the soil materials.

The Monteregian soils form a belt around the Monteregian hills and are as a rule more gravelly than the sandstone moraine soils. The normal soil in these districts is a well-drained, deep gravelly loam, acid in reaction with the organic matter extending to a considerable depth. In the ill-drained phase the subsoil is iron stained and somewhat compact. The

surface soil is very rich in organic matter. Poor drainage in most cases is due to underground seepage and springs rather than to topographical features. But seldom is the subsoil compacted sufficiently to cause an impervious layer. This phenomenon is only found at considerable depth (4 feet or more), so that it is of little significance in orchards of the Monteregian hills region.

The third apple growing district discussed in this paper, is in the Appalachian foothills. The mineral parent material of these soils differs greatly from that of the soils of the two previously discussed districts. Iron sandstone and angular shale and schist gravels are the dominant mineral soil forming materials. The normal well drained soil is quite acid in reaction and slightly podsolized, belonging to the typical grey brown forest soils. As a rule these soils are high in nitrogen content and fairly well supplied with potassium. They are deep gravelly loams, which are very suitable for orchard growing under the climatic conditions in Quebec. The ill-drained phases of these soils are in many cases caused by seepage and underground springs rather than topographical relief, although the latter is of greater importance than in the Monteregian soils. In the ill-drained soils there is a strong tendency for the subsoil to become compact and to resist the free movement of water. This condition has been referred to as "hardpan formation." The term "hardpan" may not be applicable in the correct sense of the word, since this compacted condition often extends to considerable depth. The exact nature of this "hardpan" formation is not yet fully understood and more work will have to be done to clarify this question. It is believed, however, that soluble silica plays a very important part in causing this compacted condition. From our present knowledge, soils in which this "hardpan" condition appears close to the surface are not to be recommended for orchard planting.

The river and marine soils are found in old lake beds and river channels. They are at a lower level than the glacial-deposited soils and the latter have often a great influence on the development of the lower lying alluvial soils. To the river and marine soils belong the beach sands, which formerly formed the beaches of the old lakes and sea. They are also often found in old river channels. They usually are found near the lower slopes of the moraine soils. In the acid regions, around the Monteregian hills and the foothills of the Appalachian hills, these sandy soils are usually podsolized to varying degrees. Only in a few cases was the B horizon, which is the zone of accumulation, found to be compact enough to cause difficulties.

Where the surrounding moraine soil is calcareous in nature, the sands are not podsolized and form a deep, open soil. With proper fertilization and management some good apple orchards can be grown on these deep, well drained sandy soils.

The sedimentary clay soils are usually found adjacent to the sandy beach soils. Due to their low positions, drainage is as a rule more difficult than on the rolling and hilly glaciated soils. They are only seldom planted to apple orchards. However, where underdrains have been installed, some good orchards were encountered.

In conclusion it may be said that the majority of the old apple orchards were planted on a normal, well drained deep soil.

Quebec Orchard Soil Types

A. Glacier-carried soils
  I. Sandstone moraine loam
    1. Normal soils *a*. (textural classification)
    2. Ill-drained soils (textural classification)
    3. "Hardpan" soils (textural classification)

  II. Monteregian hill soils
    1. Normal soils (textural classification)
    2. Ill-drained soils (textural classification)
    3. "Hardpan" soils (absent in orchards) (textural classification)

  III. Soils of the Appalachian foothills
    1. Normal soils (textural classification)
    2. Ill-drained soils (textural classification)
    3. "Hardpan" soils (textural classification)

B. Alluvial, River and Marine soils
  I. Sandy beach soils
    1. Sandy podsol
    2. Sands and sandy loams

  II. Clays
    1. High lime sandy and heavy clays
    2. Low lime sandy and heavy clays

Résumé

Adaptation des vergers de pommiers du Québec aux types spéciaux de sols. P. C. Stobbe, Collège Macdonald, P.Q.

Les sols des vergers du Québec présentent de grandes différences, dues à la nature de matières minérales qu'ils renferment ainsi qu'aux conditions d'égouttement. Les sols de moraine, à vase de grès, contiennent une forte proportion de chaux libre qui tend à cimenter le sous-sol lorsque l'égouttement se fait mal. Les sols montérégiens se composent de terre franche, profonde, graveleuse et acide, convenant parfaitement pour la culture du pommier. Les sols au pied des monts Appalaches sont légèrement podsolisés et tendent à former un sous-sol très compact lorsqu'ils sont mal égouttés. La chaux n'est pas l'ingrédient de cimentation dans ce dernier cas. C'est sur les sols profonds et bien égouttés que les vergers font la pousse la plus vigoureuse.

SOME PHYSICAL PROPERTIES OF VIRGIN MINERAL SOILS OF QUEBEC

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A number of interrelated physical properties have been measured for a group of mineral soils of Quebec. The samples were taken by horizons from five classes of virgin soil, viz., upland podsol, lowland podsol, brown earth, heavy clay, and sandy clay. The analyses consisted of the following measurements: mechanical analysis by the International (pipette) method; mechanical analysis by the hydrometer method; loss on ignition; organic carbon (a measure of the organic matter); moisture in air dry soil; moisture taken up by soil at 50% relative humidity; maximum moisture taken up by 100 gm. soil (moisture holding capacity); absolute and apparent specific gravity; pore space; volume expansion and heat of wetting. Determinations were also made of minimum water of saturation for some of the samples.

Scatter diagrams show that the following soil constants are each correlated with organic carbon content (and loss on ignition) in approximately the order named: 1, maximum moisture holding capacity; 2, moisture taken up at 50% relative humidity; 3, moisture content at the sticky point; 4, pore space; 5, heat of wetting; 6, volume expansion.

Scatter diagrams and calculations show that the above-mentioned soil constants are by no means so closely correlated with clay content as they are with the organic carbon (organic matter content).

By the method of least squares, equations have been obtained showing to what extent clay content and organic matter content contribute to the other soil constants. If the soil constants are represented thus: organic carbon, C; clay, K; maximum moisture holding capacity, M; moisture taken up at 50% relative humidity, R; moisture at the sticky point, S; heat of wetting, H; and volume of expansion, V; the equations are:—

$$
\begin{aligned}
M &= 59.6 + 0.176\,(K-27.5) + 7.76\,(C-3.29)\\
R &= 2.73 + 0.0258\,(K-27.5) + 0.365\,(C-3.29)\\
S &= 39.6 + 0.0961\,(K-27.5) + 4.807\,(C-3.29)\\
H &= 4.21 + 0.036\,(K-27.5) + 0.448\,(C-3.29)\\
V &= 13.7 + 0.130\,(K-27.5) + 1.21\,(C-3.29)
\end{aligned}
$$

The probable errors of the coefficients have been determined and tested for significance.

Expressed in percentages the dependence of the various values upon clay and organic content are as follows:—

In order to be significant (P = .05) the percentage dependence must be approximately twice the bracketed value. It is evident that organic matter has considerably more influence than clay.

Soil constant	Dependence on clay	Dependence on organic matter
M	14.3% (±10.5%)	85.7% (±19.4%)
R	34.1% (±10.7%)	65.9% (±14.6%)
S	12.8% (± 7.3%)	87.2% (±14.2%)
H	37% (±12%)	63% (±15%)
V	44% (±20%)	46% (±23%)

The authors wish to thank Dr. D. K. Froman and Dr. R. R. McKibbin for their generous assistance in this work.

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PASTURE CONSERVATION AND IMPROVEMENT

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A fertilization experiment was begun in 1923 to test the merits of basic slag, superphosphate, ground limestone, nitrate of soda alone, and a combination of superphosphate and ground limestone as a top dressing for old pastures.

At that time the growth on the pastures was largely bent grass and poverty grass. Moss was abundant and there was practically no white clover. Although the weather the previous year had favored pastures, 21 heifers lost an average of 28 pounds while at pasture. Grain was fed to the milch cows all summer and it was necessary to supplement the pastures for cows on test with either green feed or silage except for six weeks in the flush period.

Basic slag, superphosphate, ground limestone alone, and a combination of superphosphate and ground limestone were also tried on new seeded pasture in 1929. These treatments were all on mowed plots and every treatment increased yields but in no case was the increase sufficient to be profitable.

Basic slag was also tried in 1923 on land grazed with sheep; 750 pounds per acre were applied. A second application at the same rate was made three years later. The first application was disappointing. The second application definitely increased carrying capacity, but not enough to justify the amount of fertilizer used.

Pastures were fertilized with 350 pounds of 16% superphosphate or the equivalent, and 100 pounds of muriate of potash per acre, using nitrogen to stimulate growth in 1928. This treatment improved the pasture to such an extent that supplementary feeding of either green feed or silage has been rarely necessary since that year, and the feeding of mill feed has been greatly reduced. All pasture fertilization experiments now carried on have been either suggested or modified by the results of that work.

A series of plots were laid out in 1929 to serve as a check on the fertilized pastures and to study the effect of nitrate of soda. One hundred pounds per acre at commencement of growth gave best results. One and two further applications of 50 pounds nitrate of soda per acre at a month to 6 week intervals were rarely economical.

In 1931 the experiment was modified to study the effect of applying minerals every year, every 2 years and every 6 years.

Nitrate of soda was most effective when minerals were applied each year. Minerals alone gave fair increases when applied every 2 years. Applying minerals every year increased cost of fertilizer 100% and increased yields only 72%.

In all experiments, with one exception, when minerals were applied every 2 years the plots top-dressed with nitrogenous fertilizer gave fair to good increases in yield at every cutting the year minerals were applied. The year minerals were not applied the increase in yield for that season was nearly all obtained in the flush period.

The highest yield and cheapest gain per ton dry matter has been from the heaviest potash fertilization, viz. 100 pounds per acre.

[1] Assistant to Superintendent.

Nitrate of soda has given best results of any source of nitrogen tested but the difference between sources was not striking. Top-dressing with ground limestone increased the effectiveness of sulphate of ammonia.

A placement fertilizer experiment was begun in 1935 to see if grasses and clover would root more deeply if superphosphate and potash were put below the surface, and also if superphosphate would be more available.

Work with pure pasture species and mixtures indicates that:—

1. When land is properly fertilized and closely grazed there is no advantage in sowing an expensive pasture mixture.
2. Timothy is a much under-rated pasture grass.
3. Wild white clover is superior to either Dutch or mammoth white clover for pasture.
4. Some grasses *e.g.* rough stalk meadow grass favor the growth of clover.
5. New Zealand orchard grass has possibilities as a pasture grass.

Lime alone has always slightly increased yields, but in some instances complete fertilizer has been more effective on unlimed plots than on plots which have been top-dressed with lime at rates ranging from 1 to 4 tons per acre. The pH of the untreated soil of the field in which these tests were conducted ranges from 5.2 to 5.6.

The amount of fertilizer necessary to give best returns, profit and yield considered, is probably much lower for grazed pasture than results on mowed plots seem to indicate, because when pastures are grazed a large percentage of the plant food eaten returns to the pasture in urine and feces. Therefore, all the fertilizer plots laid down the last 3 years are partly grazed. In some experiments plots are grazed and yields taken from cages. In other experiments one-half of the plot is grazed and the yield taken from the other half, the mowed grass being fed to sheep on the grazed half of each plot. After the second cutting each year, the grazed half becomes the mowed half until after the second cutting the next season.

We firmly believe that no system of pasture improvement can be profitable or permanent unless the soil has sufficient available minerals. We further believe that the excellent pastures at this station are only partly due to the abundant water supply and the favorable climate, but more particularly are the result of liberal applications of phosphoric acid and potash.

Résumé

Conservation et amélioration des pâturages. J. M. F. MacKenzie, Station expérimentale fédérale de Fredericton, N.-B.

Des essais de fertilisation de pâturages ont été entrepris en 1923. La production de l'herbe n'a pas augmenté d'une façon économique après l'application de scories basiques, de superphosphate, de pierre à chaux broyée, de nitrate de soude seul, et d'une combinaison de superphosphate et de pierre à chaux broyée, mais l'augmentation a été satisfaisante lorsqu'on se servait d'engrais contenant de l'azote, du superphosphate et de la potasse. Le nitrate de soude s'est montré le plus efficace de tous les engrais azotés sans que la différence soit frappante cependant; son action était d'autant plus forte quand il était appliqué au printemps et au commencement de la pousse. Le superphopshate et la potasse, appliqués tous les ans et tous les deux ans, ont provoqué une assez bonne augmentation de rendement. Lorsque les pâturages sont bien engraissés et broutés de près, il n'y a pas d'avantage à semer un mélange couteux de graines d'herbe à pâturage. Les excellents résultats obtenus sur les pâturages à la Station de Fredericton sont en grande partie le résultat d'applications généreuses d'acide phosphorique et de potasse.

PASTURE IMPROVEMENT

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In the month of June, 1935, with 19 cows in milk and 3 dry cows, and charging pasture at the rate of $2.00 per head per month, the feed cost of milk production for the herd was 28 cents per hundred, and for butterfat 7 cents per pound. In the month of January, 1935, with 22 cows in milk and 3 dry cows, the feed cost of milk production for the herd was $1.12 per hundred, and for butterfat 29 cents per pound.

Fertilization increased the carrying capacity of pastures at the Dominion Experimental Station, Fredericton, N.B., over an average of seven years by 61.53 per cent. Under the new system of calculating the carrying capacity, by giving credit for the total digestible nutrients supplied by the pastures, fertilization increased the carrying capacity 100 per cent in 1935. The yield of dry matter obtained from caged areas in the same fields for an average of three years was 3,096 pounds per acre from the unfertilized field, and 7,652 pounds and 6,804 pounds per acre respectively from the limed and unlimed sections of the fertilized fields.

On May 12, 1936, the milch cows were turned to pasture during the day and on May 18, they were turned out night and day. No grain was fed after May 20. On May 11, production from 23 cows was 683 pounds milk. On June 11, the same 23 cows produced 756 pounds of milk.

For the 1928 and 1929 grazing seasons and every other year thereafter up to 1935, 350 pounds of 16% superphosphate or its equivalent and 100 pounds muriate of potash per acre have been applied. The first year, more nitrogenous fertilizer was applied but from then on, 150 pounds nitrate of soda have been applied annually. The treatment has been changed to include small annual applications of complete fertilizer, as well as heavy applications of minerals every four years with nitrogen every year, and also heavy applications of minerals every four years with no nitrogen.

Fertilized pastures should be grazed closely early in the season to prevent grasses from heading and to encourage growth of white clover. Do not over-graze later in the season. Rest the pastures when necessary. Provide supplementary feed to bridge the period of short pasture.

It is suggested that a pasture field be selected for improvement that is close to the farm buildings, where there is a supply of water, and that an amount up to one-half acre for each milch cow be fertilized.

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